Guyot

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RECENT PROGRESS IN THE THAWING OF FROZEN GRAVEL IN PLACER MINING

BY

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RECENT PROGRESS IN THE THAWING OF FROZEN GRAVEL IN PLACER MINING.

By Charles Janin.

INTRODUCTION.

Dredging methods for gold placers and the construction and operation of gold dredges were described in Bulletins 121[1] and 127[2] of the Bureau of Mines. The working of frozen gravels, a special problem in placer mining, has received much attention in Alaska and the Yukon Territory, and the methods evolved there are described in this paper.

In placer mining in the far North one of the greatest difficulties encountered is the permanently frozen condition of the ground. In the early days of mining the ground was thawed by the primitive method of building wood fires on the surface, at the bottom of a shaft, or at the face of a drift. Although this method was slow and costly, a more effective one was not discovered until about 1898, when Mr. C. J. Berry[3] noticed that the steam escaping from the exhaust of a hoisting engine had thawed a hole in the solid "muck." Mr. Berry picked up the exhaust pipe (a rubber hose), applied it elsewhere, and found the steam thawed the ice and moss so rapidly as to permit the full length of the hose to penetrate the ground within a few minutes. Further experiments followed. At first a rifle barrel and then a short piece of iron pipe, pointed at one end, was used for penetrating the ground, rubber hose being attached to convey the steam. The direct application of steam through points proved so effective that it became the chief method adopted in thawing many millions of cubic yards of gravel for drift, surface mining, and dredging operations.

As a result of experiments, changes were made in the shape of the steam point, better methods of application were devised, and the best number of points to be used in a unit and the distances at which points should be spaced to get the maximum benefit were determined.

The largest mining operations in frozen gravel were those of the Yukon Gold Co., near Dawson. Detailed figures of operation and cost, given on page 5, represent the best practice for the methods employed.

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[1] Jennings, Hennen, The history and development of gold dredging in Montana, with a chapter on placer-mining methods and costs, by Charles Janin: Bull 121, Bureau of Mines, 1916, 63 pp.

[2] Janin, Charles, Gold dredging in the United States: Bull. 127, Bureau of Mines, 1918, 226 pp.

[3] Rickard, T. A., Thawing frozen gravel with cold water: Min. and Sci. Press, vol. 120, March 13, 1920, pp. 364–365.

Tests with hot-water thawing, the point being supplied with hot water instead of steam, were made at different times. A number of these experiments indicated that ground could be thawed by this method, but in comparison with steam thawing the latter was generally found more effective. At all events, no extensive thawing with hot water was ever done. Comparative tests of hot-water and steam thawing are described elsewhere in this paper. It should be recognized that steam by contact with the frozen ground condenses to water, gradually giving up its heat units and having much the same effect as an application of hot or warm water. In the same manner, water that is applied hot soon loses most of its heat.

Purington[4] mentions the use of hot water under pressure at a drift mine in the Klondike and says that at that mine a hot-water nozzle thawed more ground than was thawed in the Klondike by the average steam point. Experience in general, however, favored steam.

Payne[5] performed some experiments for the Yukon Gold Co. and advocated thawing frozen gravel with hot water.

In all, many millions of cubic yards of frozen ground have been mined in the northern fields of Alaska and the Yukon Territory, as well as Siberia, by using various methods to soften or thaw the gravel. As has been said, the most satisfactory method developed was thawing with steam points. This method, however, proved slow and costly under the most efficient management, its cost amounting in general to about 40 per cent of the total cost of mining, and at some mines to perhaps 70 to 80 per cent. The high cost of thawing required that the gravel mined contain a much higher gold content than ground that could be profitably mined where thawing was unnecessary, and prevented the working of the lower-grade ground in the frozen areas.

The working of most of the deeper—40 feet or more—frozen or partly frozen ground seemed economically impossible except where drift mining would be profitable. A number of gravel areas in the far north have attracted mining men because of the high gold content as compared to dredgable areas of unfrozen ground in other districts. Little attempt to work much of this gravel has been made until recently, however, as no cheap method of thawing was known. A number of experiments have been made from time to time since the beginning of placer mining in the far North with the purpose of de-

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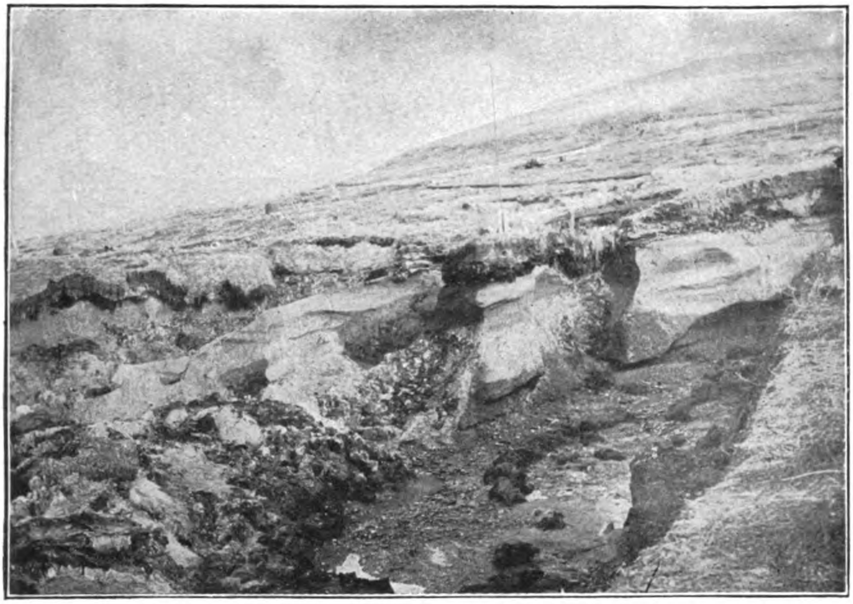
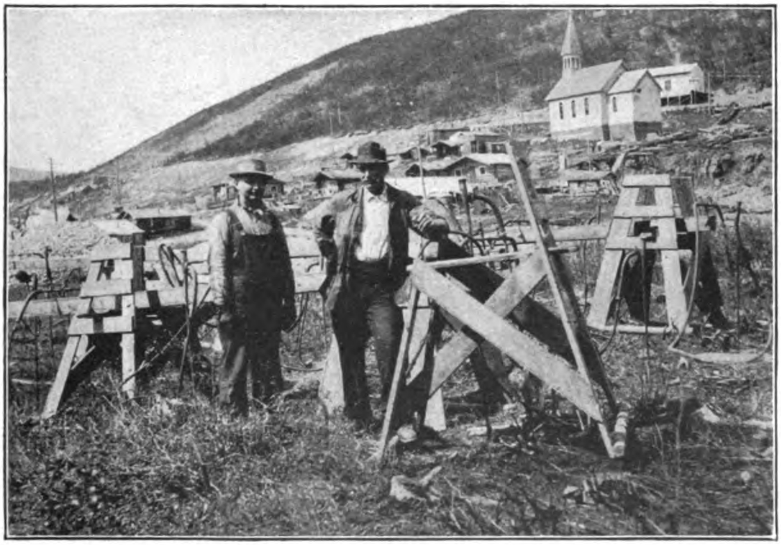
[4] Purington, C. W., Methods and costs of gravel and placer mining in Alaska: U. S. Geol. Survey Bull. 263, 1905, p. 93.

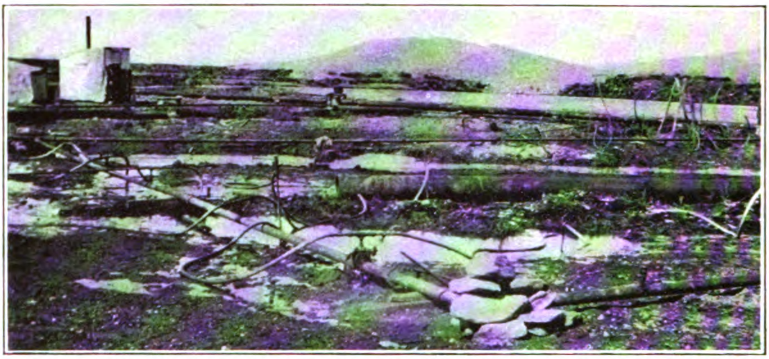
[5] Payne, H. M., The development and problem of the Yukon: Trans. Canadian Min. Inst., vol. 16, 1913, p. 237.



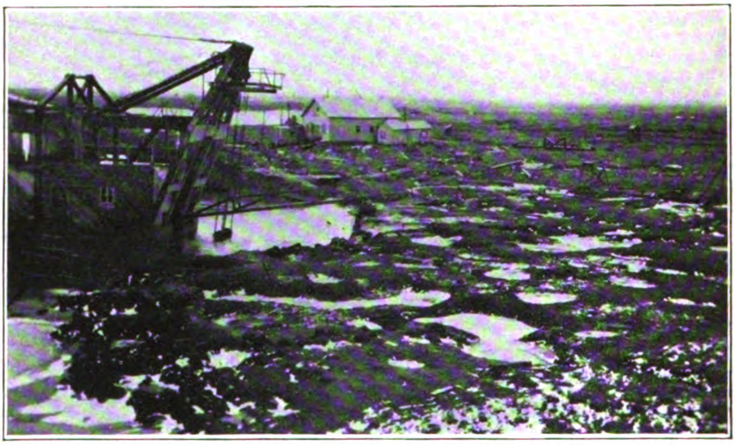
A. OVERBURDEN ON PLACER GROUND, NOME DISTRICT, ALASKA.



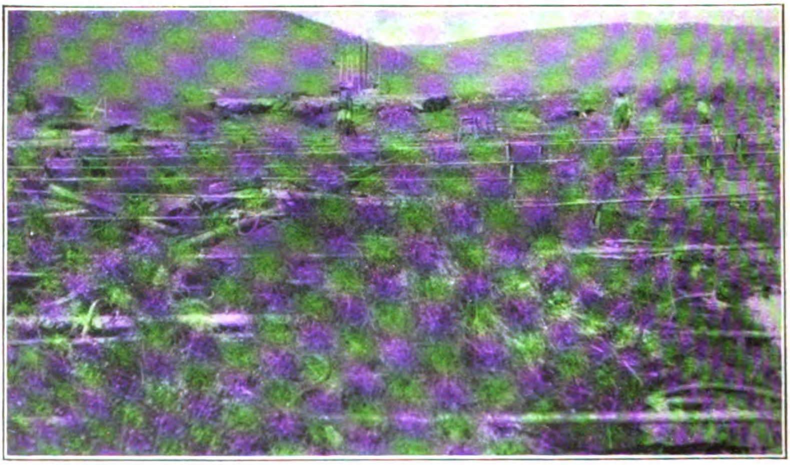
B. THAWING WITH STEAM POINTS ON BONANZA CREEK, YUKON TERRITORY.



A. LAYOUT OF THAWING EQUIPMENT ON PROPERTY OF ALASKA MINES CO., NEAR NOME, ALASKA.



B. GROUND IN FRONT OF DREDGE OF ALASKA MINES CO., NOME, ALASKA, THAWED BY USE OF WATER UNDER NATURAL TEMPERATURE.



C. COLD-WATER THAWING; PLANT IN OPERATION ON DOMINION CREEK, YUKON TERRITORY, CANADA; THE NORTH WEST CORPORATION, LIMITED, SUMMER OF 1921.

veloping a more efficient method of thawing the frozen ground, and the files of the Patent Office show drawings of some peculiar machines designed for that purpose.

USE OF WATER FOR STRIPPING.

Though some experiments were made with cold water—that is, water at natural temperature—instead of steam or hot water, these were mostly to dispose of the overburden of muck. The extensive operations of the Yukon Gold Co. and the Canadian Klondike Co. in the Dawson field, as well as the Pioneer Mining Co. in the Nome district, showed that getting rid of the muck overburden was not difficult where there was a water gradient. The method of treatment was as follows:

A layer of vegetation on top of the muck was burned where possible, or removed by water under hydraulic pressure. In some places a top soil was first loosened by means of strong plows drawn by tractors, and then hydraulicked. After removal of this top layer the muck overburden, about two-thirds ice, mixed with sand and clay, was exposed.

Water led by ditches from surface streams or gathering ditches was turned on this muck, and gradually thawed or cut channels through it and the frozen gravel. This left the muck in blocks and ridges, and further thawing was aided by the sun. The work was facilitated at open-pit workings, if a bank was exposed. Water under hydraulic pressure was then used to thaw completely the overburden and to get rid of it. Under these conditions it was not difficult or costly to dispose of the muck in advance of mining operations. The success of this method led to expectations that the same system could be applied to the frozen gravels. Some claims were made that once the overburden was removed, the underlying gravel and bedrock would readily thaw under the heat of the summer sun. These claims, however, proved fallacious. Numerous articles were written on this subject about 1914. From one by E. E. McCarthy[6] a number of extracts have been taken for this paper.

RELATIONS OF "MUCK" AND GRAVEL.

Most of the dredging ground in the far North is covered with an overburden called "muck," which is composed of 25 per cent to 40 per cent organic matter and 60 per cent to 75 per cent ice; its thickness ranges from a few inches to 40 feet, the greater depth being in the gulches. For further information the reader is referred to a paper by Tyrrell.[7] Plate I, *A*, shows muck in the Nome district; Plate I, *B*, shows steam thawing in the Fairbanks district.

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[6] McCarthy, E. E., Stripping frozen gravel: Min. Mag. (London), vol. 10, April, 1914, pp. 289-295.

[7] Tyrrell, J. B., Frozen muck in the Klondike district: Trans. Roy. Soc. Canada, ser. 3, vol. 11, 1917, pp. 39-46.

Muck is defined by McCarthy [8] as—

> A frozen substance having the following physical characteristics: Color, gray to black; composed of organic matter, particles of sand and silt, cemented by ice. In hardness it may be likened to a soft sandstone. The temperature of the frozen muck varies between 19° and 24° F., or 8° to 13° below the freezing point. The average physical characteristics are as follows:
>
> *Physical characteristics of muck.*
>
> | | |
> |---|---|
> | Specific gravity | 1.392 |
> | Specific heat | .192 |
> | Weight of 1 cubic foot, pounds | 87 |
> | Weight of solids in 1 cubic foot, pounds | 49.33 |
> | Volume of solids in 1 cubic foot, per cent | 31.9 |
>
> The figures are taken from a number of experiments made in 1912 by engineers in the employ of the Yukon Gold Co.
>
> The weight of the frozen gravel per cubic foot has been found from the average of a number of experiments to be 137.3 pounds, of which 17.4 pounds is ice and 119.9 pounds solid. The temperature varies between 18° and 22° F., averaging 19°. At one place, where it was possible to get a reading 38 feet below the surface, a temperature of 2° F. was recorded. The temperature of the frozen bedrock varies between 8° and 14°, averaging 11½° F. * * *
>
> It is true that in almost all cases where there is an overburden of muck, the underlying gravel is frozen; also, where areas of thawed ground have been found, there has been little or no overburden of muck. However, there are many areas free from muck that are frozen from immediately below the seasonal frost line to bedrock. Evidence from thousands of drill holes and holes made with crowbars seems to prove that the transition from the frozen to the thawed condition is gradual and in the form of a curve, and these curves always slope toward a drainage channel. Although it can not be said with certainty, all the data point to the conclusion that, unless the creek has an established drainage channel to bedrock to carry the water from the melting of the ice in the frozen gravel, thawing will proceed with extreme slowness, and complete thawing will not result until such a channel is established. The layers of clay found in the gravels in some places, and the varying proportion of clay in gravels rendering some more impervious than others, are important factors in the rate of thawing. The Yukon Gold Co. has carefully prospected practically all its properties for frost by means of Keystone drills and steel bars. From the data obtained colored maps have been made showing the outline of the frozen, thawed, and partly thawed areas. To the eye the map of each creek looks like a crazy quilt. The only noticeable feature is that the thawed areas are almost invariably connected to a thawed bedrock channel.

An attempt to obtain one of these maps of thawed and frozen areas, which would be of much interest in studying this subject, proved unsuccessful, as the maps, it is understood, were destroyed in a fire at Dawson.

In discussing the early work of the Yukon Gold Co., McCarthy [9] says:

> STRIPPING EXPERIMENTS OF YUKON GOLD CO.
>
> During the seasons of 1906, 1907, and 1909, the Yukon Gold Co. conducted some large-scale experiments with the removal of muck overburden. The tests were conducted at three different points on Bonanza Creek, where every convenience was at hand. Two 5-inch giants under 400-foot head were used at one point, and an additional supply of 3,000 miner's inches was available on Bonanza Creek after it had been used in the hydraulic mines. No trouble was experienced in getting rid of the muck in favorable localities, but the solid matter was deposited a short distance from the operation and had to be driven along. The serious drawbacks were that nothing could be done with the areas that were covered with a tailing of sand and gravel on top of the muck, within the limits of reasonable expense. As the cross ditches cut down to a base level, they lost grade, and more and more hand labor had to be employed. Buried roots and stumps had to be cut out by hand at great expense.

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[8] McCarthy, E. E., Article cited, p. 289.

[9] McCarthy, E. E., Article cited, p. 293.

Original from PRINCETON UNIVERSITY

I have endeavored to show that the stripping alone had its serious difficulties and that it can not be accomplished with the ease and cheapness to be inferred from recent articles on this subject. We now approach the main question: Will the creek gravel and bedrock thaw after the overburden is removed? Is the method practicable and will it reduce the ultimate cost of dredging?

The experiments of the Yukon Gold Co. above described were sufficient to demonstrate to our satisfaction that the method of stripping and so-called actual thawing could not be relied upon for any large-scale operation. The stripping work on claims Nos. 89 and 90 on Bonanza Creek was of no benefit to the dredging operation. Practically all of the ground had to be thawed by steam before the dredges could operate. The ground was stripped and exposed for an average of less than a season before dredging was attempted. On claims Nos. 78 and 79, opposite Trail Gulch, where main-ditch water was used for stripping, the ground was approximately 50 per cent thawed when reached by the dredge a season and a half later. On account of incomplete data, it is not possible to say positively how much of the thaw was due to stripping and how much of the ground was naturally thawed previously. It is my opinion, from the data available, that the proportion of complete thawing due to stripping was small and altogether disproportionate to the expense of doing the work. The same comments apply to the work on Nos. 62 and 63 Bonanza. In this case the stripping was more thorough and the ground was exposed for an average of over three seasons. The dredge reports show that 50 per cent of the ground was frozen and had to be thawed by steam.

STEAM THAWING OF MUCK AND GRAVEL.

The cost of steam thawing has been from 15 to 20 cents or more per cubic yard, according to the locality, the cost of fuel, the depth of the frozen ground, and the extent of the operations undertaken. The operations of the Yukon Gold Co. in the Dawson district in the years 1909 to 1920, inclusive, during which time over 45,000,000 cubic yards of gravel were dredged and over 26,000,000 hydraulicked, have been the largest operations for mining gravel by these methods in the far North.

METHODS OF YUKON GOLD CO.

The following description by Perry[10] of the method of steam thawing followed by the Yukon Gold Co. is of interest as indicating the best practice known until recently.

> Operations in the Yukon district are subject to difficulties which are not met elsewhere, except in Alaska and Siberia. These may be described under two heads: (1) Climatic; (2) character of deposits.
>
> The extreme cold of the northern winter limits the operation to an open season of about six months. Dredging can not be begun until there is sufficient thaw to produce water for flotation and to clear the ponds of the winter ice, which forms to a depth of from 5 to 7 feet. Both the start and the finish of the seasonal operation are hindered by cold. All moving parts, such as the tailings conveyor, must be housed in and warmed by steam coils. Also, steam is used to freely keep the ladder and bucket line clear and to keep the gold tables in good condition. The dredging operation is terminated when the creeks freeze to such an extent that water for flotation is no longer available. * * *
>
> The greatest problem in the Yukon as compared to the ordinary dredging operation has come in the handling of frozen ground. The heavy bedrock encountered on the creeks and the necessity of digging it to considerable depth to recover the gold was in itself a serious matter. * * * When this was further complicated by having large areas solidly frozen, the problem of dredging such areas at a profit became one of extreme difficulty. The result of attempts to dredge partly thawed areas and frozen bedrock showed that the frozen condition must be completely changed before dredging

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[10] Perry, O. B., Development of dredging in the Yukon territory: Trans. Canadian Min. Inst., vol. 18, 1915, pp. 26-44.

could be successful. * * * Preparing the frozen ground for dredging by thawing with steam was an entirely new feature of dredge mining.

The improvements that have been made in steam thawing since it was adopted for large-scale dredging operations are too many to attempt to detail in a short paper. They have taken the following general lines: First, reduction in fuel; second, increase of efficiency of hose and points; third, reduction in cost of driving. * * *

The steam point as originally used was a short piece of ⅜-inch pipe, drawn down at one end to a point with an orifice left for the steam to escape; the other, or head end, had a nipple welded to it for steam-hose connection. The point, with steam turned on, was gradually driven into the face of the drift, then allowed to steam until the bedrock and gravel were thawed to the height of the drift. From two to six points were used in each breast, spaced from 1 to 2 feet apart. This simple operation contained the essential features of the method whereby over 3,000,000 yards of gravel are now being thawed in a season.

In the thawing operation for dredging, the points are driven from the surface down through muck and gravel and into the bedrock from 4 to 6 feet. The points were gradually lengthened in practice, first, to 24 feet, then to 30, and last season were being successfully driven 40 feet to bedrock. The points are made up of triple extra strong hydraulic pipe with drop-forged head and tool-steel tip. The small boilers first used have been replaced by larger sizes until the boiler equipment now comprises eight plants with a total boiler horsepower of over 2,000. The 150-horsepower locomotive type has been adopted as the unit, and the plants usually consist of a pair or, sometimes, three such boilers.

The preliminary work for each season takes the following form: (1) The dredgable area ahead of each boat is barred for frost. From the bar-hole results the naturally thawed and frozen areas are blocked out. The bar tests are checked by drilling where thought necessary. (2) Surveyors "pick up" the thawed areas which are mapped, and the planimeter measurements are made of the frozen areas. (3) The estimated course of the boat is laid out for the year and its probable position calculated for each month of the season. (4) The total square yards of frozen ground which the dredge will dig in a season is measured from the map on which the season's work is laid out; then the necessary amount of wood for thawing is determined and its location is decided.

The thawing operation has been described elsewhere,[11] so that I need only give the sequence of events in a normal operation: (1) Steam-line boxes are strung out by horses, if they are available, otherwise men are used; (2) gooseneck boxes and headers coupled on; (3) bar holes for starters put down; (4) starters used to thaw holes about 8 feet deep; (5) starters pulled and long points placed in starter holes; (6) points driven down through gravel and into bedrock; (7) points allowed to steam in bedrock from 12 to 48 hours, depending on the formation; (8) points pulled, cleaned, and straightened; (9) header moved and starters put down and cycle begun again. * * *

Costs vary. Thawing on Hunker Creek, for example, is much more difficult and expensive than thawing on Bonanza. In 1911 the thawing for dredge No. 4 on Hunker Creek cost $2.18 per square yard as against $1.85 ahead of the No. 5 on Bonanza. The depth being practically the same, the cost of thawing per cubic yard was much greater in one case than in the other. Purely local conditions govern this cost, such as depth of ground, character of material, ease or difficulty in driving, time of steaming, cost of fuel, etc. Since the gold, practically speaking, is all confined to the bedrock, the cost per square yard of bedrock exposed by the thawing becomes the controlling factor in determining what ground can be dredged at a profit and what must be left.

One plant of the Yukon Co., in 1908, consisted of three boilers, two 150 horsepower and one 75 horsepower, fired with wood that cost $8 per cord delivered. The steam gage on the boiler registered a pressure of 150 pounds. By the time the steam reached the gravel the pressure had decreased to 25 pounds per square inch. The main pipe line was 3½ inches in diameter, wrapped in asbestos packing and encased in a wooden box packed with sawdust. From the main line the steam was taken several hundred feet in 1½-inch branch pipes to where the ground was to be thawed. At intervals of 8 feet along a branch pipe short lengths of hose connected the pipe to the heads of the steam points.

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[11] Rickard, T. A., Dredging in the Yukon; Min. and Sci. Press, vol. 97, Sept. 12, 1908, pp. 354–356.

This hose was armored, $\frac{5}{8}$ inch in diameter, and long enough to reach the heads of the points when they were being swung into position.

The steam points consist of $\frac{3}{4}$ to 1 inch pipe, cut into 14 to 20 foot lengths. Both ends of the point are of steel, the lower end having a $\frac{3}{16}$-inch opening to permit the steam to escape and the upper end having a driving head. The steam point is generally started by driving a steel crowbar into the ground until the frozen gravel is struck. Then the bar is withdrawn and the steel point introduced. The head of the steam point is pounded with a 4-pound hammer and given an occasional twist to aid its sinking into the gravel. This is done at intervals and in rotation throughout the entire battery of points. The ground is softened by the admission of the steam and the average rate of thawing is about 2 feet an hour. Should a bowlder be encountered in depth, it is necessary to withdraw the point and drill through the bowlder with a steel bar unless the point is equipped with a steel bit for the purpose of cutting through the bowlder. With a battery of 150 or more points the cost of thawing under the above conditions may run from 12 to 20 cents a cubic yard.

The appended tables show the thawing and dredging cost for six years of the Yukon Gold Co.'s operation. Table 4 shows the variation in working cost for the different dredges in one season. Because of the conditions changing, the dredge that has the lowest cost for one season may show the highest cost for the next. When the costs for he eight dredges are totaled and averaged the results over several seasons are remarkably uniform.

While Table 1 shows a gradual reduction in the thawing cost, it does not reflect the improvement in efficiency, which has been very marked.[12]

TABLE 1.—*Thawing cost, Yukon Gold Co., 1909–1914.*

Year.	Total (square yards).	Frozen (square yards).	Naturally thawed (square yards).	Naturally thawed (per cent).	Thawing cost.	Thawing cost per square yard.
1909	298,061	212,903	85,158	28.6	$275,112	$1.5571
1910	396,837	256,033	140,804	35.5	500,689	1.7727
1911	555,393	432,693	122,700	22.1	696,034	1.6166
1912	692,522	509,574	182,948	26.4	804,854	1.455
1913	651,505	445,624	205,881	31.6	685,570	1.546
1914	586,737	402,660	184,077	31.4	602,174	1.428

TABLE 2.—*Dredging and thawing costs, Yukon Gold Co.*

Year.	Ground dredged (cubic yards).	Thawing cost per cubic yard (cents).	Percentage of thawing cost of total.	Total cost per cubic yard (cents).
1909	2,381,880	15.45	48.37	31.94
1910	3,249,788	14.14	45.57	31.09
1911	4,151,249	17.62	49.72	35.43
1912	5,157,280	15.02	49.03	30.64
1913	5,133,575	13.57	45.94	29.53
1914	4,800,781	12.18	44.09	27.62

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[12] Perry, O. B., Development of dredging in the Yukon Territory: Trans. Canadian Min. Inst., vol. 1915, pp. 26–44.

TABLE 3.—*Detail of 1913 thawing costs.*

	Total expenditures.	Cost per square yard (cents).	Percentage of total cost.
Fixed salaries	$1,614.00	0.4	0.23
Labor	289,195.38	65.2	42.18
Fuel	295,928.03	66.7	43.17
Shop expense	1,722.16	.4	.25
Preliminary expense	36,021.74	8.1	5.25
Material and supplies	23,180.50	5.2	3.38
Stables	6,589.27	1.5	.96
Transportation	198.00	.1	.03
Miscellaneous	380.33	.1	.06
Depreciation	30,731.37	6.9	4.48
Power	9.45	....	.01
	685,570.23	154.6	100.00

Square yards thawed, 443,567.
Number of points driven, 63,004.
Cost per point driven, $10.881.

TABLE 4.—*Thawing and dredging costs of individual dredges of Yukon Gold Co.*

Dredge.	Creek.	Percentage of area naturally thawed.	Thawing cost per cubic yard (cents).	Total cost per cubic yard (cents).
No. 1	Bonanza	22.1	12.55	31.93
No. 2	do	34.6	12.28	32.55
No. 3	do	14.0	18.36	33.79
No. 4	Hunker	7.2	17.95	32.11
No. 5	Bonanza	44.8	12.34	27.01
No. 6	do	18.6	16.38	33.36
No. 8	Upper Bonanza	33.7	12.97	27.92
No. 9	Eldorado	58.6	7.49	21.16

METHODS USED IN THE CAPE NOME DISTRICT.

An article by Arthur Gibson,[13] on thawing frozen ground for different forms of placer mining is quoted below as of particular interest in comparing the cost and the efficiency of the methods known in 1913:

> The following efficiency and cost data are collected from actual placer-mining operations in the Cape Nome mining district, Seward Peninsula, Alaska, but will apply to other localities of like nature by proper adjustment of the cost of fuel, labor, board, and local conditions. One frequently hears that it costs so many cents per cubic yard to thaw frozen ground in a certain locality. These statements, although in many instances true and derived from actual operations, are misleading in that the cost per cubic yard may not only vary with different localities but may even vary considerably in the same locality and within short distances. The principal factors governing the cost of thawing are as follows: (1) Amount of ice contained per cubic yard, (2) cost of fuel, (3) cost of labor, (4) amount of condensation due to long and poorly insulated pipes, (5) amount of condensation due to low temperatures during the winter, (6) method of mining or application, and (7) the scale upon which operations are conducted.
>
> ### HEAT REQUIRED TO THAW FROZEN GROUND.
>
> The temperature of perpetually frozen ground on Seward Peninsula, so far as known, remains nearly constant around 28° above zero Fahrenheit, or 4° below the freezing point, excepting close to the surface, where the temperature is affected by the atmos-

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[13] Gibson, Arthur, Thawing frozen ground for placer mining: Min. and Sci. Press, vol. 108, Jan. 17, 1914, pp. 143–145.

pheric heat or cold during the summer and winter seasons, or in the immediate proximity of subterranean water channels or thawed ground. I will assume that the frozen gravel deposit contains 2.850 pounds of solids and 260 pounds of ice per cubic yard, and it is desired to heat this deposit from 28° above to 36°, or to a temperature 4° above the freezing point. How much heat is then required, expressed in B. t. u.'s per cubic yard?

The coefficient of thermal capacity (specific heat) for solids is 0.2, that for ice is 0.5, and that for water is 1. The latent heat of fusion of ice is taken at 142 B. t. u. per pound. Then:

	B. t. u.	
2,850 pounds of solids raised 8°, from 28° to 36°, 2,850 × 8 × 0.2		4,560
260 pounds of ice raised 4°, from 28° to 32°, 260 × 4 × 0.5	520	
260 pounds of ice at 32° to water at 32°, 260 × 142	36,920	
260 pounds of water raised 4°, from 32° to 36°, 260 × 4 × 1	1,040	
Total heat required for the ice		38,480
Total heat required per cubic yard of ground		43,040

This plainly illustrates the rapid increase of heat required for only a small increase of ice per cubic yard, and it shows further that under these conditions the ice requires 92.5 times as much heat as the solids. With crude oil of a fuel value of 18,000 B. t. u. per pound, or 142,416 B. t. u. per gallon, or with coal of a fuel value of 12,000 B. t. u. per pound, and assuming the efficiency of boiler and distributing plant at 50 per cent, there will be required in the above example to thaw one cubic yard of frozen ground:

$$\frac{43{,}040}{9000} = 4.782 \text{ pounds of crude oil, or}$$

$$\frac{43{,}040}{71{,}208} = 0.604 \text{ gallon of crude oil, or}$$

$$\frac{43{,}040}{6000} = 7.173 \text{ pounds of coal.}$$

The variation in the cost of fuel noted in the accompanying data is due partly to the fact that in general the prices have been raised during the last year, although some unexpired contracts maintain the former and lower prices, and partly to the different freight rates, which are proportional to the various distances between the supply station at Nome and the mines, being lower during the winter than the summer season.

The cost of labor for this particular work, firemen and pointmen, is $3.50 and $4, respectively, during the winter, and $5.50 and $6, respectively, during the summer season. Board, including fuel and cooks' wages, ranges from $1.08 to $1.35 per man per day, according to the number of men employed.

The table presented contains only the actual operating expenses, no charges for management, interest on investment, or depreciation of the outfit being considered or included. Nos. 1 to 5, inclusive, are the figures for underground stope mining where the steam points are used in a horizontal position. No. 6 contains the data with regard to thawing ahead of a dredge where the steam points are used in a vertical position.

The fuel used in all of the above cases is California crude oil, averaging 17.5° Baumé, weight 7.912 pounds per gallon, and containing 18,000 B. t. u. per pound, or 142.416 B. t. u. per gallon.

The foregoing data are compiled from the common practice among some of the best miners on Seward Peninsula, Alaska, but which could no doubt be improved under scientific management. Judging from the fuel consumption, it is evident that it requires from 80 to 100 per cent more fuel during the winter than during the summer for underground drift mining. Fuel for thawing ahead of a dredge appears very high. This is principally due in this case to the ground, which contains between 60 and 85 per cent ice. Labor, duty per man per day for thawing, varies to a great extent, as it depends largely on the composition of the deposit, whether it is sand, light or coarse gravel, or ground containing large rocks which render the driving of the steam points difficult.

Miners frequently overlook some of the most vital factors relative to the most efficient and economical means of thawing, such as ascertaining and gaging the proper distance between the steam points; the correct time of steaming; the proper time for the dirt to lie idle between thawing and excavation to evenly absorb and equalize the heat transmitted. The success of the venture depends greatly on the proper adjustment of these factors. The thawing of deep ground for dredging purposes has so far proved more or less unsuccessful, due principally to the steam condensing and losing its greatest heating value before reaching the end of the steam point. This, however, is only a matter of application and can be adjusted under a proper system.

Comparative data on efficiency and cost of thawing frozen ground with steam for placer mining in Cape Nome mining district, Alaska.

	Joe Wise & Co. (Joe Wise, mgr.). 1	Joe Wise & Co. (Chas. A. Vogel, mgr.). 2	Joe Wise & Co. (Chas. A. Vogel, mgr.). 3	New Eagle Mining Co. (A. B. Brown, mgr.). 4	Otto Olson, operator. 5	Plein Dredging Co. (J. F. Plein, mgr.). 6
Operated during	Winter.	Summer.	Summer.	Summer.	Summer.	Summer.
Class of placer mining	Underground driving and stoping.					Dredging.
Depth below surface	53 ft.	81 ft.	81 ft.	45 ft.	50 ft.	9 to 20 ft.
Thickness of pay dirt	2.5 ft.	2.5 ft.	2.5 ft.	3.5 ft.	2 ft. 2 in.	....
Thickness of waste	1.5 ft.	2 ft.	2 ft.	1.5 ft.	2 ft. 4 in.	....
Total depth of stope	4 ft.	4.5 ft.	4.5 ft.	5 ft.	4.5 ft.	....
Material, dirt and clay	....	....	....	....	....	7 ft.
Material, gravel	4 ft.	4.5 ft.	4.5 ft.	5 ft.	4.5 ft.	7.5 ft.
Swelling of loose dirt, per cent	26.8	....	....	....	....	[1] 25
Number of boilers	1	2	2	1	1	2
Total boiler horsepower	45	70	70	35	50	85
Steam points, length	7 ft.	7 ft.	7 ft.	6 ft.	7 ft.	9 to 20 ft.
Steam points, number	40	90	90	25	46	40
Steam points working	Horizontal.	Horizontal.	Horizontal.	Horizontal.	Horizontal.	Vertical.
Steaming time, hours	9	12	12	8	11	48
Horsepower per steam point	1.125	0.777	0.777	1.4	1.08	2.125
Depth thawed, feet	8	7	9	7.5	7.5	14.5 av.
Left to absorb heat, days	1	2	2	....	2.5	20 to 30
Ground thawed per day, cubic yards, loose dirt	128	205	257	128.57	327.13	[1] 567.25
Ground thawed per day, cubic yards dirt in place	100.94	....	....	....	....	453.8
Duty per point per day, cubic yards loose dirt	3.2	2.278	2.855	5.1428	7.1115	[1] 14.18125
Duty per point per day, cubic yards dirt in place	2.5235	....	....	....	....	11.325
Duty per foot per hour, cubic yards loose dirt	0.051	0.02712	0.033994	0.10714	0.092326	[1] 0.040751
Duty per foot per hour, cubic yards dirt in place	0.04	....	....	....	....	0.032543
Crude oil consumed per day, barrels	4	4	4	2	5	20.95
Crude oil consumed per day, gallons	168	168	168	84	210	880
Crude oil consumed per point per thaw or day, gallons	4.2	1.867	1.867	3.36	4.567	22.00
Crude oil consumed per point per hour, gallons	0.467	0.15558	0.15558	0.42	0.4152	0.9167
Crude oil consumed per cubic yard loose dirt thawed, gallons	1.3125	0.81951	0.6537	0.65334	0.64195	[1] 1.55131
Crude oil consumed per cubic yard dirt in place thawed, gallons	1.6644	....	....	....	....	1.93918
B. t. u. consumed per cubic yard loose dirt	186,921	116,711	93,097	93,046	91,424	[1] 220,936
B. t. u. consumed per cubic yard dirt in place	237,037	....	....	....	....	276,170
Duty per barrel of oil in cubic yard loose dirt	32	51.25	64.25	64.28	65.426	[1] 27.076
Duty per barrel of oil in cubic yard dirt in place	25.235	....	....	....	....	21.66
Number of men employed per day for thawing	4	4	5	3	3	[2] 3.5
Duty per man per day, cubic yard loose dirt thawing	32	51.25	51.4	42.85	109.04	[1] 162.07
Duty per man per day in cubic yard dirt in place	25.235	....	....	....	....	129.66
Cost of crude oil per barrel delivered	$2.97	$3.30	$3.30	$2.90	$2.71	$2.52

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[1] Assumed values based on excavated dirt swelling 25 per cent over dirt in place.

[2] Number of men employed per day thawing ahead of the dredge is given as 3.5. This is thus explained: The night pointman also acts as oiler on the dredge during the night and his time is thereby divided into one-half for the thawing and one-half for the dredge.

Columns No. 1, 2, and 3 refer to the Linda Association claim on Center Creek; No. 4, bench 1, Center Creek; No. 5, the Tundra Association; and No. 6, the Otter Creek property.

Original from PRINCETON UNIVERSITY

Comparative data on efficiency and cost of thawing frozen ground with steam for placer mining in Cape Nome mining district, Alaska—Continued.

Average total cost per day.

	Joe Wise & Co. (Joe Wise, mgr.) 1	Joe Wise & Co. (Chas. A. Vogel, mgr.) 2	Joe Wise & Co. (Chas. A. Vogel, mgr.) 3	New Eagle Mining Co. (A. B. Brown, mgr.) 4	Otto Olsen, operator. 5	Plein Dredging Co. (J. F. Plein, mgr.) 6
Crude or fuel oil	$11.88	$13.20	$13.20	$5.80	$13.55	$52.79
Labor and board	20.50	27.82	34.90	20.45	21.05	25.73
Repairs and renewals	7.50	7.50	7.50	2.50	7.50	3.89
Rent, 50-horsepower boiler						1.67
Total operating cost	39.88	48.52	55.60	28.75	42.10	84.08
Average cost per cubic yard loose dirt.						
Crude or fuel oil ... cents	9.28	6.44	5.13	4.51	4.14	9.31
Labor and board ... do	16.01	13.57	13.58	15.91	6.44	4.54
Repairs and renewals ... do	5.86	3.66	2.92	1.94	2.29	.68
Rent, 50-horsepower boiler ... do						
Total operating cost per cubic yard loose dirt ... cents	31.15	23.67	21.63	22.36	12.87	[1] 14.82
Total operating cost per cubic yard dirt in place ... cents	39.51					18.53

[1] Assumed values based on excavated dirt swelling 25 per cent over dirt in place.

THAWING WITH WATER AT NATURAL TEMPERATURE.

About 1915 to 1917, different persons started experiments on an entirely new plan for thawing the frozen gravel. Water at the natural summer temperature was applied by drilling holes through the frozen muck and gravel to bedrock and the water was allowed to find its way through the gravel back to the surface. This water was taken from surface ditches, or through pipes under pressure, or pressure was obtained by pumping. The results of these tests were very satisfactory.

During 1917, and thereafter, experiments in cold-water thawing were made in the Dawson field by the Yukon Gold Co. and the Canadian Klondike Co., in Nome by John H. Miles of the Alaska Mines Corporation, on Candle Creek by Edward Pearce, and possibly in other districts by persons at present unknown to the writer. Certainly it seems, as has been true of many discoveries, that a number of men at different places were following similar ideas at the same time. Nearly all the men reported that the results of their experiments were successful. Miles, one of the first to attempt a practical use of the knowledge gained, was the first to apply for a patent for the method he developed, a United States patent, 1,339,036, being granted him May 4, 1920, on the method of thawing ground. Following the result of these experiments, operations on a working scale were carried out both in the Dawson field by the Yukon Gold

Co. and the Canadian Klondike Co. and in Nome by engineers acting for the Alaska Gold Corporation, and through the courtesy of these companies the results of these experiments were made available for this paper.

Although there is still much to be learned regarding practical application of the method, thawing with cold water has passed the experimental stage and is being proved of great value to the gold-mining industry.

The successful application of this method where water is obtainable under pressure without pumping will make large areas of so-called low-grade ground available for dredging, and ground that has previously been considered to be of little or no value will now be of economic importance. Had the knowledge of this method of thawing been available to the Yukon Gold Co. and other companies operating dredges in the far North during the past 10 years, there might have been a considerable saving in costs and a correspondingly additional profit to those companies.

EXPERIMENTS OF J. H. MILES IN CAPE NOME DISTRICT.

As an introduction to the study of cold-water thawing, an abstract of an article by W. S. Weeks [14] is given. This article, which was prepared by Mr. Weeks at the request of J. H. Miles, describes various tests carried on by Mr. Miles in the Nome district. The result of these tests led to Miles adopting cold-water thawing as the most efficient method of softening the frozen gravel before mining. Several other articles on thawing frozen ground which have recently appeared in the technical press are given below; also information obtained from operating companies, this information never having been published, which should be of value to those interested in mining in the far North because the figures show results from operations and not merely expectations based on small-scale experiments. Excerpts from Mr. Weeks' article follow, with Mr. Miles' observations substantially represented by the material in quotations:

"The equipment consisted of a 12-horsepower boiler and a superheater, made of several coils of 2-inch pipe with brick and sheet-iron housing. The first experiment was with superheated steam. Three points of $\frac{3}{4}$-inch double extra-heavy pipe drawn down to $\frac{5}{16}$-inch opening at one end were used. Two of the points were lowered into 6-inch churn-drill holes. The third was put down in the following manner: A 1-inch double extra-heavy pipe drawn down to $\frac{1}{4}$-inch opening at one end was used; a clamp was placed around the pipe, and a weight having a hole in the center was slipped over the pipe and attached to the walking beam of a Keystone drill, which raised and dropped the weight, striking the clamp and forcing the pipe. The pipe was rotated slightly at each blow by use of a Stillson wrench. Warm water at 20-foot head was forced through the pipe, thawing and softening the ground at the point. In this manner the pipe was driven 42 feet in 4 hours and 10 minutes.

"In the following season a combination rotary percussion drill was developed, consisting of a 2-inch pipe with a serrated steel shoe, using cold water at 80-pound pressure flowing through a pipe. The pipe made 20 revolutions per minute, and an 80-pound weight, which dropped 60 times per minute, helped to force it down. With this machine it was possible to sink the 2-inch pipe 40 feet in 1 hour and 20 minutes. The pipe used in this machine is left in the ground and used as a thaw pipe, the high-pressure water being replaced with low-pressure water at whatever head is available. This machine proved satisfactory for the soft formation. In like formations of shallow depth it is not necessary to force the pipe down by mechanical means; the pipe will sink of its own weight if rotated slightly by hand. * * *

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[14] Weeks, W. S., Thawing frozen gravel with cold water: Min. and Sci. Press, vol. 120, March 13, 1920, pp. 367 370.

"The results of the superheated steam thawing were most unsatisfactory. After steaming for a few hours the ground around the pipe began to sink, forming a pool of hot water, and the longer the thawing proceeded the hotter the water became. It became evident that with so much heat coming to the surface very little thawing was taking place on bedrock. The nature of the ground was such that when thawed it was possible to probe with an iron bar to a depth of about 25 feet. By using this bar it was found that the thawing in these holes was being done in the form of an inverted cone, as was subsequently proved when these thaws were dug out.

"Saturated steam for thawing was next tried, using ordinary steam points, but instead of driving with hammers, as is the common practice on shallower ground, the pipes were dropped into holes previously drilled by a Keystone machine. These tests showed very similar to superheated-steam tests, with the exception of thawing an inverted cone slightly smaller on top and extending to a greater depth.

"Hot water was tried, using three holes. A 1-inch double extra-heavy pipe with ⅝-inch outlet was used. Hot water drawn from the blow-off cock of a boiler was circulated through the pipe at an average temperature of 105°. By probing with an iron bar it was determined that this method was far more efficient than the previous steam tests from the fact of the walls of the hole being nearly parallel. But, as in the steam tests, heat units were wasted because the water failed to deliver its heat in the ground but carried it to the surface. This led Miles to think that thawing was a slow process and that it was not a concentrated heat that was necessary but a uniform circulation of water with just a few heat units to give up. It was then determined to try surface water, the temperature at that time being 52° and the temperature of the ground 28° F. Ditch pressure not being available, a steam pump was used with a 2-inch suction and ½-inch discharge. This pump delivered 20 gallons per minute at an average pressure equal to a 40-foot head. The pump was connected to a 2-inch pipe, which was dropped into a 6-inch Keystone drill hole.

"No results were apparent for 24 hours, when the 'muck' began to slough from the sides of the holes and retarded the circulation of water in the hole. From that time on one could see the progress of thawing. In 36 hours an 8-foot area was thawed, and upon probing with an iron rod it was found that the walls of the thaw were vertical, not the shape of an inverted cone, as in the steam thaws. * * * At the end of the eighth day it was decided to stop thawing on this hole and start another for a check, owing to the lateness of the season. The water entering the ground had a temperature of 52°; at the end of 24 hours the outgoing water was at 50°; at the end of 48 hours, 48°; at the end of 72 hours, 45°; at the end of 86 hours, 40°; at the end of 192 hours, 36° F. To obtain maximum efficiency, the amount of water entering the thaw pipe should be governed by the temperature of the outgoing water. Just enough water should be used to keep the temperature of the outgoing water a little above freezing.

"In watching a cold-water thaw in operation, one sees the water boiling up around the outer edge of the hole, not in the center. * * *

"The time consumed in these experiments, which included three superheated-steam thaws, three saturated-steam thaws, two hot-water, and two cold-water thaws, was from April 20 to October 25, when the weather became too cold for further experiments. Although tests with bars had given a good idea of the amount thawed and the shape of each thaw, it was decided to obtain an exact cross section of each thaw. On December 1, when the surface water had frozen so that it was possible to sink shafts without the necessity of pumping, contracts were let to parties to sink shafts over the thawed test holes in order to ascertain the exact amount of material thawed and the shape of each hole. This work was finished on December 20, 1917.

"The results of these experiments will be found in the accompanying chart. (See Fig. 1.) The cold-water thaw was most advantageous because, first, it thaws a larger area on bedrock, and into bedrock itself for a considerable distance, thereby making it possible for dredges to clean the bedrock without encountering the frozen pinnacles and the frozen spots which are invariably left by the present method of steam thawing.*** Secondly, the heat units needed to thaw are supplied by nature; consequently, ground in the outlying districts, where it has been impossible to procure fuel for steam thawing, can now be thawed at no greater expense than ground near a fuel supply, thus opening for the prospector and operator a large area of the frozen North.

"Thirdly, the actual cost of thawing in ground chosen for the experiments, or ground much deeper, was estimated by Miles to be less than 1 cent per cubic yard. * * *

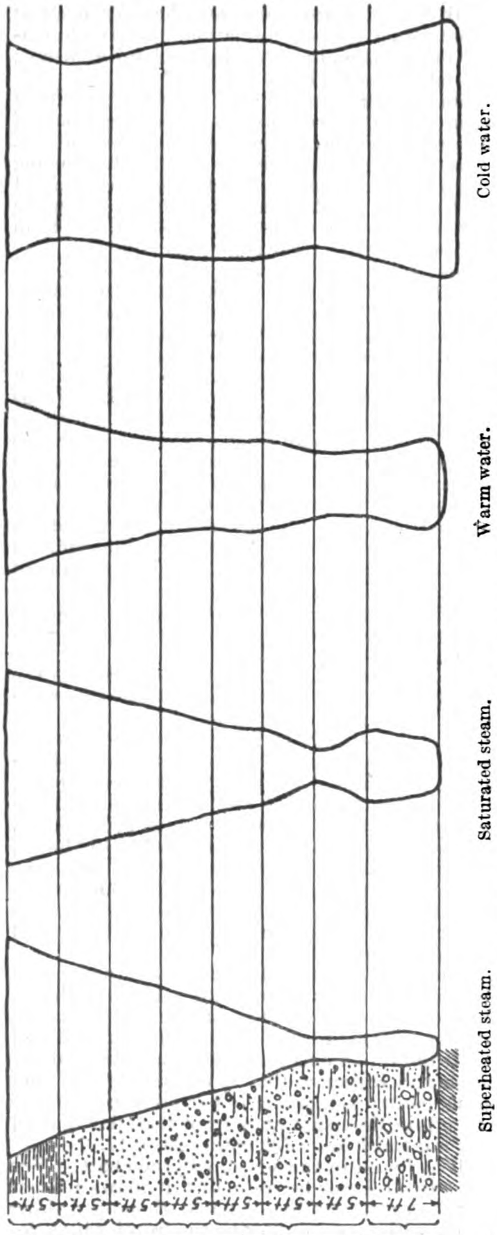

FIGURE 1.—Results of thawing with superheated steam, saturated steam, warm water, and cold water.

"In the spring of 1918 Miles had occasion to thaw a block of ground 130 feet long by 80 feet wide by 11 feet deep, composed of pure beach sand. It was arranged to compare the difference in time between steam and cold-water thaws in actual operation, so a battery of 12 points was constructed, using steam from a 20-horsepower boiler. The men employed were experienced in steam thawing, working two 12-hour shifts. At the end of the third day an area 20 feet square was partly thawed—that is, was thawed on the surface—but by prodding down with a bar one could feel lumps of frozen ground. Steam thawing was stopped and a 4-inch centrifugal pump used, the discharge pipe having twelve 1-inch openings. To each opening a 12-foot length of 1-inch garden hose was attached and on the end of each hose a piece of common 1-inch pipe 12 feet long. There was hardly any pressure at the end of the pipe, probably not over 1 pound. The pipes were held up by hand until they had sunk about 1 foot into the sand, then they were left to sink into the sand as they thawed. In 12 minutes the pipe would sink through 11 feet of sand. The hole around the pipe would be about 6 inches in diameter. The pipe was left in the hole 30 minutes longer, then the hole was about 36 inches in diameter. The pipe would then be drawn and started in a new hole. It was found best to move the pipe after about 45 minutes, as the water seemed to start circulating under the 11-foot cap of frozen sand and the thawing action on the sides of holes was retarded. With these twelve 1-inch pipes two men thawed the remainder of the area and also rethawed the ground partly thawed by steam in four days and nights. The whole area was thoroughly thawed."

In brief, thaws were "put in" with superheated steam, saturated steam, hot water, and cold water. In each case the thawing medium was introduced at the bottom of a churn-drill hole. When the surface water was frozen, shafts were sunk on the drill holes and the volume of the thaw determined. The chart (Fig. 1) shows the cross section of a thaw of each type.

From the point of view of the heat units involved, the following is of interest:

The gravel at the place where the experiments were made weighed about 3,000 pounds per cubic yard, and each cubic yard contained about 300 pounds of ice.[16] Nearly all the heat used in thawing frozen ground is consumed in melting the ice, so for this approximate calculation the small amount of heat used in raising the temperature of the solid material may be neglected. In the steam and hot-water thaws the information taken about the available heat is the amount of oil used. It seems reasonable to assume an efficiency of 50 per cent for the boiler and the delivery system. The experiments in the order in which they appear on the chart (Fig. 1) are as follows:

EXPERIMENT 1.—*Superheated steam.*

Hours	156
Gallons of oil	1,755
Cubic yards thawed	109

To determine what proportion of the heat supplied in the steam was used in thawing, hourly quantities were taken in order that the figures may be less unwieldly.

Gallons of oil per hour	11.25
Cubic yards thawed per hour	0.7
B. t. u. per gallon of oil	140,000

If a boiler efficiency of 50 per cent is assumed, 70,000 B. t. u. will be available for thawing for every gallon of oil used.

B. t. u. necessary to melt 1 pound of ice	144
B. t. u. supplied per hour (11.25×70,000)	787,500
B. t. u. necessary to melt ice per hour (0.7×300×144)	30,240

Efficiency of absorption......... $\frac{30,240}{787,500}\times 100$ per cent=3.8 per cent.

EXPERIMENT 2.—*Saturated steam.*

Hours	98
Gallons of oil	882
Cubic yards thawed	83
Gallons oil per hour	9
Cubic yards thawed per hour	0.85
B. t. u. supplied per hour (9×70,000)	630,000
B. t. u. necessary to melt ice (0.85×300×144)	36,720

Efficiency of absorption....... $\frac{36,720}{630,000}\times 100$ per cent=5.8 per cent.

EXPERIMENT 3.—*Hot water.*

Hours	67
Gallons of oil	405
Cubic yards thawed	81
Gallons of oil per hour	6.04
Cubic yards thawed per hour	1.21
B. t. u. supplied per hour (1.21×300×144)	52,272

Efficiency of absorption......... $\frac{52,272}{422,800}\times 100$ per cent=12.3 per cent.

EXPERIMENT 4.—*Cold water.*

Hours	192
Water per minute, gallons	20
Cubic yards thawed	511

In this case the available heat units are assumed as follows:

Water per hour, gallons	1,200

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[16] Experiments by others have indicated more ice in a cubic yard of frozen gravel.

Cubic yards thawed per hour	2.66
Temperature of water introduced, °F	52
B. t. u. per pound of water theoretically available (52 — 32)	20
B. t. u. given up per gallon (20 × 8.35)	167
Total heat available, B. t. u (2.66×300×144)	144, 912

Efficiency of absorption......... $\frac{114,912}{200,400}\times 100$ per cent=57.4 per cent.

To summarize: Of the total heat applied in each experiment the following proportion was approximately used in doing the useful work of thawing:

	Per cent.		Per cent.
Superheated steam	4	Hot water	12
Saturated steam	6	Cold water	57

A study of the steam thaw shows that the clay was penetrated only to a slight extent. The description would indicate that most of the heat in the steam was expended in keeping hot a comparatively quiet pool of water. There could have been very little circulation of the hot water, because a 12-horsepower boiler will evaporate only about 1 gallon of water per minute.

The hot-water thaw shows uniform thawing but low efficiency. The efficiency of the heat absorption increases as the area of frozen ground in contact with the thawing medium increases. This is clearly shown in the temperatures of the outgoing water in the cold-water thaw. If the hot-water thaw had been continued as long as the cold-water, then the efficiency doubtless would have been much greater.

The cold water apparently accomplishes all that is desired and at slight expense. Clay is no impediment. A vigorous circulation must be maintained, so that the cooled water is quickly removed and replaced by more, which has a few heat units to give up.

TEST BY ALASKA MINES CORPORATION.

After the experiments by Miles in the Nome district a comprehensive test of cold-water thawing on a working scale was undertaken for the Alaska Mines Corporation in 1919 by the Hammon Engineering Co., of San Francisco. Through the courtesy of one of the principals in the Alaska Mines Corporation the results of the experiments were made available for this paper. Mr. Edwards, chief engineer for the Hammon Co., in summing up the results, says:

> Cold-water thawing was given a thorough try out with satisfactory results. The costs when handled on a large scale will be under 4 cents per yard.

Plate II, *A*, shows the layout of the thawing equipment, and Plate II, *B*, the thawed ground in front of the dredge. (See p. 3.)

The experiments and the results are summarized as follows:

> The equipment used comprises one 25-horsepower boiler; one double-acting 4-inch pump, 6 by 10 inch steam end, 4 by 10 inch water end, and 9-inch stroke, supplying water for points giving pressure of 60 pounds. Temperature of water going into points averages 54° and of water returning from bedrock 34°.
>
> Points used were made up of double extra-strong ¾-inch and 1-inch pipe cut in lengths of 12 feet special-cut threads, special-made couplings, and connected together as they were driven down. For the driving of points a slotted anvil, or driving head, weighing 80 pounds, was keyed on pipe at any desired height with grip wedges. This anvil, or driving head, was made from 8-inch shafting, cut in 6 to 8 inch lengths, with handles inserted on opposite sides for turning the point back and forth while working it down; when hard material is encountered, the head is hammered with an 8-pound hammer while the pipe is being turned as in drilling. The anvil, or driving head, can also be made from old bucket pins.
>
> For the driving end cruciform steel was used; it was cut about 6 inches long, with a ½-inch hole through the center, sharpened to a chisel-bit edge and welded on end of the pipe. This style bit cut rapidly and with less danger of the point going down at an angle; also it successfully drills through bowlders. Water under pressure flowing through the bit keeps the thawed material from the bit and supplies sufficient water for circulation through the ground.

It is found that the points must not be driven too fast but that time should be allowed for the ground to thaw and to keep the bit free as it goes down, thus eliminating the danger of plugging the point, which would necessitate pulling same and losing the hole. Therefore, from the data on different sets it is found that two men working from point to point in rotation can cut down to bedrock five to six points as quickly as one point worked on continuously; the time for making connections with hose and coupling together of pipe as driven down has taken an average of 10 minutes to each coupling. All this can be shortened with a more adequate equipment.

Two centrifugal pumps, one 8-inch and one 10-inch, were used to supply water. For shallow thawing common ¾-inch iron pipe without a bit on end was found to be sufficient as they worked down by hand very readily to depth of 9 and 15 feet. The length of time points were left in ground ranged from seven to eight days. On the third day the ground around the point would start sinking, and as a rule on the fifth day it would have sunk to a depth of 5 feet, but points were left in seven days before pulling and resetting. On account of the ground having sunk, leaving a lake of water around points, it was difficult to test the ground with a drill to determine the extent of thawing, so this was left until dredge reached it.

As the dredge did not encounter any frost in the deep thawed ground, it was decided that seven days was enough to thaw 45 to 50 feet of ground with points set at 10-foot centers. Points set at 16-foot centers driven to bedrock, and left seven days before pulling, showed that while the ground had sunk around the points, there was an unthawed space of about 2 feet between thawed points. This frozen ground was getting soft, showing that a day or two longer would have thawed the entire block. Zero weather set in and it was necessary to shut down and pull the points. It was thought that points set with 16-foot centers would thaw successfully in 10 to 12 days under ordinary conditions, and estimates of thawing costs given in this report will be based on a spacing of 16 feet. The yardage controlled increases rapidly from the 10-foot centers to the 16-foot centers, being 138 cubic yards at the 10-foot and 363 cubic yards at the 16-foot centers.

In driving points in ground 60 feet deep, heavy wash completely frozen, there was no perceptible difference in driving to bedrock. To determine the minimum cost of thawing is difficult, as the equipment used this year was inadequate, requiring not only the expense of pumping water for points, but also of raising the temperature of the water going to the points, as the water in the pond (supply for this summer) had a temperature of 44°.

From experience it was determined that pressure is necessary for success in driving points. Both 40 and 60 pound pressure were tried and better success found in using 60 pounds. High pressure largely eliminates the danger of plugging the points while driving them and gives greater circulation of water.

By using the Wild Goose ditch it is figured that both the quantity of water required and a pressure of 69 pounds is obtainable, thereby avoiding the expense of pumping and of extra equipment. Temperatures, taken at different times, of the water in the ditch have averaged 61° F. and from past records this summer has been cooler than the average. Therefore, the temperature of the ditch water in a normal summer season will be higher. It is planned to do all the thawing necessary for one season's operation in 90 days of summer.

The following table gives a comparison between the first and last sets of thaw points put down to bedrock by six men on the first set and by four men on the second set:

Cost data on thawing with points, 1919.

Set A.—10 points at 10-foot centers, 6 pointmen.

Driving time per point, hours	2.7
Distance per hour, feet	16.1
Area thawed per point, square feet	86.6
Ground thawed per point, cubic yards	140
Average depth, feet	43.6
Average water pressure, pounds	60
Average temperature of supply water at point, ° F	54
Average temperature of return water from point, ° F	34
Pulling time, minutes	30

Set B.—Points at 10-foot centers, 4 pointmen.

Driving time per point, hours	1.04
Distance per hour, feet	41
Area thawed per point, square feet	86.6
Ground thawed per point, cubic yards	140
Average depth, feet	43.6
Average water pressure, pounds	60
Average temperature, supply water at point, ° F	54
Average temperature, return water from point, ° F	34
Pulling time, minutes	30

Actual cost, exclusive of piping, of thawing per cubic yard with pumping plant; points set at 10-foot centers; points to be left in 10 days after reaching bedrock.

Item.	Rate per hour.	Total cost per hour.
1 foreman	$0.67	$0.67
4 pointmen	.54	2.16
1 roustabout	.54	.54
1 pipe fitter	.60	.60
1 helper	.54	.54
1 fireman	.60	.60
Board	.75	.75
Fuel oil	.80	.80
Electric power	1.95	1.95
Miscellaneous	.10	.10
Cost per hour		8.71

Driving time, 1.04×$8.71, cost per hour=$9.05 cost per point.
Cubic yards thawed per point, 138, or 6.5 cents per cubic yard.

Costs with points set at 16-foot centers.

Cubic yards per season	700,000
Time required to thaw, days	12
Number of holes, 43-foot ground	1,986
Cubic yards per hole	363

Item.	Rate per hour.	Total cost per hour.
1 foreman	$0.67	$0.67
2 ditchmen	.50	1.00
6 pointmen	.54	3.24
1 roustabout	.54	.54
1 pipe fitter	.60	.60
1 helper	.54	.54
Board	.83	.83
Miscellaneous	.70	.70
Upkeep of ditch	.69	.69
Overhead expense, superintendence, etc	.....	1.76
		10.57

Driving time, 1.04, ×$10.57, cost per hour=$11, cost per point.
Cost per cubic yard, 3.03 cents.

First cost and depreciation.

Estimated cost of material in layout for one dredge	$26,348.00
Annual charge for interest and depreciation	5,888.00
Annual charge for interest and depreciation, per point	2.96
Annual charge for interest and depreciation, cubic yard	.82

Cost per cubic yard.

	Cents.
Labor	3.03
Material	.82
Total	3.85

The operations of the Alaska Mines Corporation during 1920, given herewith, are abstracted from the 1920 report of the superintendent, Mr. Rockwell.

Operations during 1920 continued 100 days, June 15 to September 22, when it was necessary to shut down because of water freezing. During the season 196,000 yards were dredged, 88,800 yards being from ground that had to be thawed and 107,245 yards from ground that did not have to be.

Cost of operations of the Alaska Mines Corporation.

	Cost per yard, cents.	Total cost.
Thawing 88,807 yards	11.5	$10,195
Power for 196,062 yards	15.6	30,598
Dredging 196,062 yards	6.7	13,186
Overhead	5.8	11,422
Total, 196,062 yards	33.3	[17] 65,402.94

Mr. Rockwell estimates that the total cost should be reduced 15 cents, of which 5 cents would be on thawing. He also says, "We have further proved this year that cold-water thawing is a success."

EXPERIMENTS OF E. E. PEARCE, IN CANDLE CREEK DISTRICT.

A summary of the experiments (see p. 30) carried on in the Candle Creek district by Edward Pearce have been abstracted from a letter written by Mr. Pearce under date of January 20, 1920, as follows:

> Three years ago I wintered in the North and did a great deal of experimenting on cold-water thawing, and from my first attempts (in a laboratory with glass tubing) to my final operations of last summer, the continuous operating of 100 points, I found the method a complete success. During the entire season of 1919 our dredge did not encounter any frost either in the gravel that had been thawed or in the bedrock, and the thaw penetrated into bedrock as far as necessary for dredging.
>
> Water was pumped from the creek to the reservoir and then brought down in a 12-inch line under a 50-foot head, the supply being divided into four units of 24 points each. It took five hours to set 25 points, the number set every day, and where there was a large overburden of muck I found it paid to use steam and water jointly. With no help from rain and with no tundra seepage, the cost per cubic yard did not exceed 6 cents. A year later experimentation in a small way was carried on in Nome, and the method was pronounced an entire success. From experiments made I can thaw more ground with 25 points, with less labor and less cost, than I did with 100 points.
>
> This is not because the 100-point plant did not do all and more than was expected from them, but it is carrying the principle of the cold-water thawing further, and utilizing the surface water in conjunction with the point water. It is along that line that cold-water thawing will be still further developed.

METHOD DEVELOPED BY PEARCE.

The following article by Pearce [18] describes the method of thawing developed by him after many experiments made in the Candle Creek district, and also gives some information on cold-water thawing in

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[17] Figures for total cost do not check, probably because of cost per yard being taken at nearest tenth; yardage may be estimated. *C. J.*

[18] Pearce, E. E., Cold-water thawing of frozen gravel; Min. and Sci. Press, Feb. 4, 1922, vol. 124, pp. 154–156

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Alaska. Mr. Pearce, as already mentioned, was one of the pioneers in this work.

This is a description of a new process for thawing frozen gravel by means of cold water, showing the methods employed and the results obtained by Iver Johnson and myself on a piece of dredging ground on Candle Creek, Alaska. Mr. Johnson and I were the first to apply the use of the small pipe in cold-water thawing operations. Prior to our use of 100 half-inch cold-water points ahead of our dredge, three holes had been drilled near Nome. Pipes of 2½ inches diameter were inserted in these holes, and cold water was used for thawing.

During the summer of 1918 we thawed a shaft 30 feet deep. This shaft was used for cold storage, and the first 25 feet was in "muck," or frozen vegetal mud. In the same year we used 40 cold-water points, each of ¾-inch diameter, and dredged the ground so thawed. In 1919 we used 100 half-inch cold-water points, set up in units of 25 points to each unit, and dredged the ground so thawed. It was during these years of experimenting on a working basis that we discovered this new process of thawing. We proved, by dredging it, that the ground had been thawed by the new process; and we found that it not only reduced the cost of thawing, but eliminated all the many elements of uncertainty attendant on thawing by any other method on a large scale. We did enough thawing with cold-water points to know the weaknesses of our system, and we saw that in deep ground it would be only indifferently successful. Some other method would have to be employed.

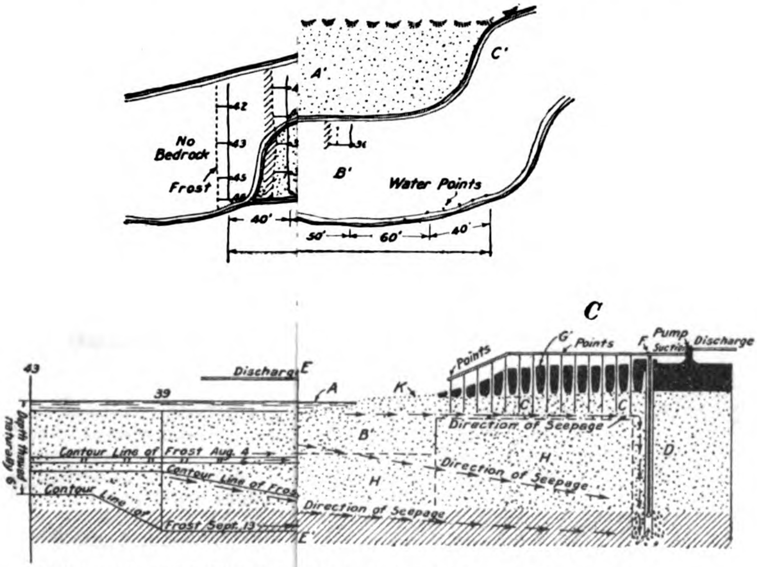
The following is a description of the new process: Plate III, *A*, shows a general plan of the ground, *A′*, *A′*, *A′* being the portion that had been dredged previously and *B′*, *B′*, *B′* the ground desired to be dug. This ground is perpetually frozen. It has no muck on the surface, but there is a layer of muck 2 feet above bedrock.

In order to confine our thawing to the area that we intended to dredge, it was necessary to turn the water of the creek *C′* over the area *B′* instead of letting it run over *A′*. Down the stream at *D D* a bar of gravel rose 2 feet above the water; and in order to get our seepage to the limits of this bar, which we were to dig, we dug a shallow ditch on each side, as shown at *E* and *E′*. Our thawing area would be then confined within the outside edges of these two ditches. If we had not dug this ditch at *E*, for instance, all the ground between the shaft *F* and the side *E* would have remained frozen, as the seepage to the shaft would all have been from the water side *E′*. It is therefore important first to block off the area to be dredged, and then see to it that there is surface water at the extreme edges, for no thawing will take place beyond the limits of this surface water.

F is a shaft sunk into the bedrock, *F′* the suction, and *F″* the pump discharge. *G* is a 2½-inch rotary pump with a rated discharge of 250 gallons per minute, and *H* is a 4-horsepower Cushman gasoline engine. The numbers 1 to 46 represent test holes driven at different times to determine the depth that the line of frost has been moved downward. The broken lines are the contours of frost at different dates. The cross sections along these test holes are represented as being taken up in place and laid horizontally on the surface of the ground.

B, Plate III, is a section taken longitudinally above and below the shaft; it shows the contour lines of frost at different dates and also the direction of the seepage. A shaft 5 by 5 feet and 9 feet deep is sunk at *F* into the bedrock. It is timbered tightly down to within about 2 feet of the bottom, and is also extended above any surface water, the whole purpose being to permit no water to enter the shaft except from the bottom. Around the sides and at the bottom some coarse gravel is thrown, to keep the fine from filling in. The shaft will fill immediately with water to the water level. The suction of the pump is dropped to within about 1 foot of the bottom of the shaft, and the water from the shaft is exhausted. As fast as this is being done, the creek water *K*, seeping through the thawed surface area *L*, follows along the frost line *M* to seek its own level in the shaft *F*, thus making a continuous flow of fresh water over the surface of the frost. As this operation is continued, so will the frost line be moved downward until it has reached the level of the bottom of the shaft. The only limits to this system of thawing upstream and sideways, are the outer edges of the surface water. It may be advisable, however, in certain instances, to sink two shafts. This can be determined only in each individual case.

In our operations last summer we found on August 4 (the day we started to pump from the shaft) that the seasonal thaw had reached a depth of 3½ feet, as represented by the contour line *M* in *B*. On August 6 the frost line had been moved downward to contour line *N*. On August 18 (the day we stopped pumping) the frost line had been moved downward through the entire area to be thawed, passing through and thawing a layer of muck, till it had reached and thawed into the bedrock.



PLAN AND SECTIONS OF ION TAKEN LONGITUDINALLY ABOVE AND
D.

The entire area, 790 feet upstream and 235 feet downstream from the shaft, with an average width of 60 feet, had been completely thawed in a period of 15 days, with an actual pumping time of 80 hours. This ground was dredged during the same summer and no “horses” of frost were encountered. The ground was thawed well and evenly. The cost per cubic yard to thaw this ground was 1.4 cents per yard, not including any overhead or equipment charges. In many parts of Alaska frozen muck and sod cover the surface of ground that is rich enough for dredging. Anyone who has mined in the North knows that, when this condition is encountered, the cost of extracting the gold will be increased materially, no matter what method may be employed. In our new process this condition will increase the cost of thawing, but not to such an extent as when thawing by any other method is adopted.

C, Plate III, represents a cross section of a piece of ground of this nature, having the creek *A* on one side, then a bare gravel bar *K*, and then a gravel bar covered with frozen muck and sod *G*. It is desired to thaw the ground between *E E′* and the shaft *F*. We do not want to thaw *D;* if we did we should move the shaft farther to the right; *A* is the water in the creek, *B′* the top gravel of the creek, naturally thawed to a depth of 3½ feet. *H H* is frozen gravel, and *G′ G* is frozen muck over the surface of the gravel. A shaft is sunk at *F* into the bedrock. This shaft will remain dry, and no thawing will take place unless a small thawed area *C* is created below the layers of muck. When this area is thawed, a seepage will be maintained from the creek *A* through the artificially thawed area *C* into the shaft *F*. The operations then are the same as they would be were there no muck, as described heretofore. In *C*, Plate I, cold-water points are used to thaw this area. The points are set in the muck to the top of the gravel only and are spaced 10 feet apart. It may be contended that as water points are used to start the thawing they might as well be used to complete the operation. This contention is wrong, for it is an entirely different matter to set points to the top of the gravel and to set them in the gravel to a depth of 15 to 40 feet. Furthermore, there is a tendency in ground of this nature for the frozen collars to extend downward into the gravel, and when thawing with points is completed there is no centainty that no frost “horses” are left.

A.—New process of cold-water thawing.

[Equipment used, cost of operations, area thawed, and cost per cubic yard thawed.]

Equipment.

One 4-horsepower gasoline engine	$135
40 feet of 2½-inch pipe	40
Tees and ells	10
Foot valve and incidentals	30
Lumber for 5 by 5-foot shaft, 9 feet deep	85
Total	300

Labor.

Digging shaft, five men for 1½ days	60
Pumping during digging of shaft, 1 day, 1 man	8
Extra man, 2 days	16
15 days' pumping from shaft, 1 man	120
	204
Distillate used, 106 gallons	60
Miscellaneous	25
Total	289

Area thawed, 790×235 feet by 60×9 feet=20,500 cubic yards, at a cost of 1.4 cents per yard.

Total time plant was in operation, shifts	15
Total time of pumping shaft, hours	89
Average mean temperature of creek, °F	64
Average mean temperature of discharge, °F	48

B.—Old process of cold-water point thawing.

[Equipment used, cost of operations, area thawed, and cost per cubic yard thawed.]

Equipment.

One 50-horsepower Union gas engine	$3,000
One Kingsford pump, 8-inch	500
800 feet of 12-inch hydraulic pipe	1,000
1,200 feet of ditch	500
240 feet of hydraulic hose, 6-inch	240
100 feet of hydraulic hose, 10-inch	100
4 units, 25 points each	150
800 feet of 1-inch pipe	80
1,200 feet of ½-inch pipe	100
700 feet of rubber hose	400
Tees, ells, unions, valves, etc	100
Total	6,170

Labor.

One pointman, 30 shifts	300
One helper, 30 shifts	240
One engineer, 25 shifts	250
	790
Distillate used, 500 gallons	300
Miscellaneous	50
Total	1,140

Area thawed, 450×80×9 feet=12,000 cubic yards, or 9½ cents per yard.

Comparative statement of Tables A and B.

	Cold-water point method.	New process.
Cost of equipment used	$6,170	$300
Cost of labor	790	204
Cost of oil	300	60
Miscellaneous	50	25
Total	7,310	589
Ground thawed, cubic yards	12,000	20,500
Cost per cubic yard thawed	$0.095	$0.014
Average thaw per shift, cubic yards	400	1,366
Time of plant in operation, days	30	15

WORK OF YUKON GOLD CO., GOLD RUN DISTRICT.

An abstract from a report on cold-water thawing operations of the Yukon Gold Co., in the Gold Run district, for the year 1920, was obtained through the courtesy of Mr. O. B. Perry. It is understood from some of the engineers of the company that much of the ground where these tests were made in 1920 had been drifted, so that these experiments would not wholly apply to virgin ground. The same thought presents itself about some of the other tests in other fields, complete details being lacking on the amount of thawed and of frozen ground, its proximity to open-working faces, and what effect these factors would have on the results. The Yukon Gold Co. found it necessary or advisable to use steam points to supplement cold water in order to start thawing early in the season and to con-

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tinue work after water thawing stopped because of the low temperature of the water.

Most of the tests in cold-water thawing were made in the months of June, July, and August. When the summer heat raised the temperature of the surface water greater efficiency was obtainable than earlier or later in the season. A large plant would be necessary to thaw enough ground during the summer to supply the dredges for their season's work.

The experiments in cold-water thawing were made by using pumps in tandem; they required considerable power, but the company had electricity available. In other districts the power cost might be much higher if the water had to be pumped, or might be considerably lower if water under natural head was available.

Steam thawing started at Gold Run on April 12 and continued until June 13. Because of delay in receiving some of the water equipment, cold-water thawing did not start until June 20; it continued until August 24, when it was abandoned because of the temperature of the water being practically at the freezing point. During this period a maximum of 812 points was operated with an average crew of about 48 men. It was possible to handle the larger number of points with a smaller crew because of the longer time required for water thawing the same number of points.

Steam thawing began again on August 21 and continued until the end of the season.

The labor cost for water thawing was higher than had been estimated because of the necessity of using the same water continually; as the water became dirty the moss and roots clogged the points and caused delay. The cost of cold-water thawing compares with steam thawing as follows:

Comparative cost of thawing with steam and with cold water.

Items.	Steam thawing.	Water thawing.
Labor	$37,271.12	$23,292.38
Power	....	1,591.09
Material and supplies	1,464.49	1,834.96
Shop expense	204.59	....
Fuel	52,844.88	89.12
Stables	2,467.68	2,401.75
Transportation	121.93	121.93
Miscellaneous	52.79	127.49
	94,427.48	29,458.69
Square yards thawed	61,832.00	27,188.00
Cost per square yard	$1.527	$1.08

Depth of ground, 25 to 30 feet; men employed, 40 to 45.

In addition to the cost of water thawing as given, there was an extra cost of $19,433 for new equipment, depreciation, and extra freighting; including these would raise the cost to $1.43 per square yard, but these charges are not included because they will not occur again. The figures are of much interest, for they show the methods of the company that perhaps has had the most experience in steam thawing, and also show the costs of cold-water thawing as determined by that company.

EXPERIMENTS OF THE NORTH WEST CORPORATION (LTD.), IN KLONDIKE DISTRICT.

In a personal communication to the author, Mr. Frederick P. Burrall, manager for the North West Corporation (Ltd.), and the Canadian Klondike Co., has given the experiments of the former company in detail. Water is supplied from a ditch line; but as there is a shortage of water during the summer, the water after use has to be pumped back to the ditch line; this extra expense would not apply at other seasons of the year. Complete figures of cost are not at present obtainable. Mr. Burrall says:

> "During 1920, the North West Corporation (Ltd.) tried out this method ahead of a dredge on Upper Dominion Creek, and the results were so satisfactory that this season a full-size plant has been established, and about 300,000 cubic yards have been thawed to date. The deposit here consists of 4 to 6 feet of gravel with an overburden of 10 to 20 feet of muck, glacial silt, and some old tailings. The cold-water points are spaced in squares of 8 feet, with the points down to bedrock. This arrangement produces a very satisfactory thaw of the gravel and bedrock, but is apt to leave the upper part of the overburden in large blocks. To overcome this, short points are placed midway between the longer points, thus (in connection with the long points) making points at intervals of 4 feet. The points are left in the ground four to eight days, according to the water temperatures and the ease with which the material thaws. Considerable difference in the action of the different materials is noted, so no particular time is fixed for the length of the thaw. Ordinary black muck and ice go very quickly, whereas fine sand and glacial silt do not thaw regularly and take twice as long.
>
> The temperature of the ingoing water varies from 40° to 70°, the latter temperature being toward the end of July, which is the period of greatest average warmth. The water coming out of the ground is about 38° to 42° F. Cutting down the velocity of the water makes the temperature of the discharge run lower, but tests have shown that when water is near 40° it is not so efficient in thawing as when it is above that temperature.
>
> The points used are of ½-inch pipe, extra heavy when obtainable, and under ordinary circumstances each point will take nearly one-half miner's inch of water. The points are connected with the "header" by ordinary molded ¾-inch water hose, fastened to the pipe with a bit of hay wire. The headers are of 1½-inch pipe, 56 feet long with ½-inch nipples welded in at 8-foot intervals. The water hose slips over these nipples and is fastened with wire. No small valves are used. The headers are connected in the center to a 2-inch connection welded in an 8-inch riveted hydraulic pipe. On each side of this connection in the 1½-inch pipe is a 1½-inch gate valve. Thus each 1½-inch valve controls four points, there being eight points on each "full-length header." The connections on the 8-inch flanged hydraulic pipe are placed 8 feet apart, and 10 full headers, equivalent to 80 points, are operated from each 8-inch pipe. Three 8-inch pipes are supplied by a 10-inch main from the water supply. The 8-inch pipes lie on the ground and the 1½-inch headers are supported by blocks or trestling, about 14 inches from the ground. (See Plate II, *C*, p. 3, and Figs. 2 and 4, showing arrangement in detail.)
>
> The water is supplied to the 10-inch main from a ditch and has a pressure of about 35 points at the 8-inch pipe. There is a shortage of water during the dry season, and water is pumped back from below the points, 2,000 feet upstream, and then elevated to the ditch. This gives the return water an opportunity to absorb some heat from the air before it again reaches the points.

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At Granville, on Dominion Creek, there is a deposit of 26 feet of gravel with 12 to 14 feet overburden. This overburden has been washed from several million cubic yards of the gravel, and natural thawing has taken place for a depth of 8 to 20 feet.

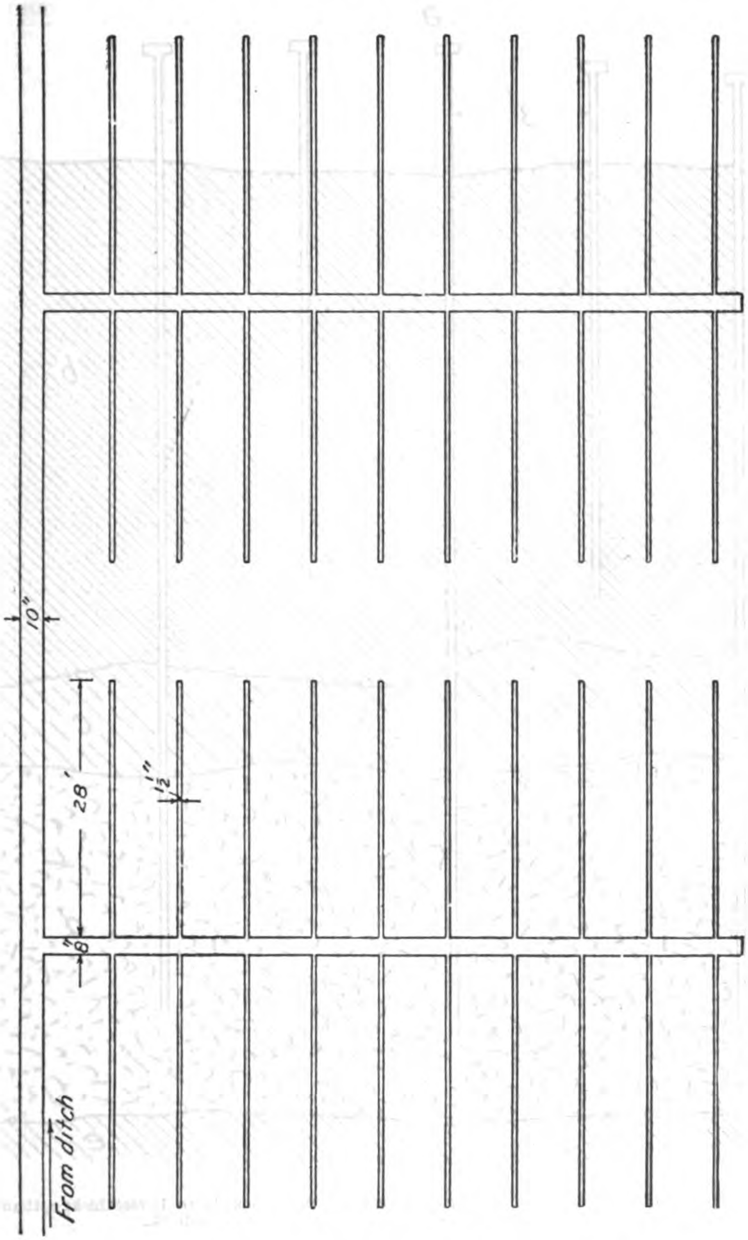

FIGURE 2.—Pipe layout for cold-water thawing on Dominion Creek, Yukon, August, 1921. The North West Corporation, Ltd.

The ground remaining to be thawed is bedrock and 6 to 18 feet of gravel above it. A similar equipment to that described above is used, except that on account of difficulty in getting the points through the gravel, they are driven with light sledges. To protect the pipe, a light head fastened to the pipe with an extra-heavy pipe coupling is used. The water being supplied from a ditch, the pressure is about 50 pounds per square inch.

Hardened points are not used on the pipes, as it was found difficult to withdraw the pipes when this was done.

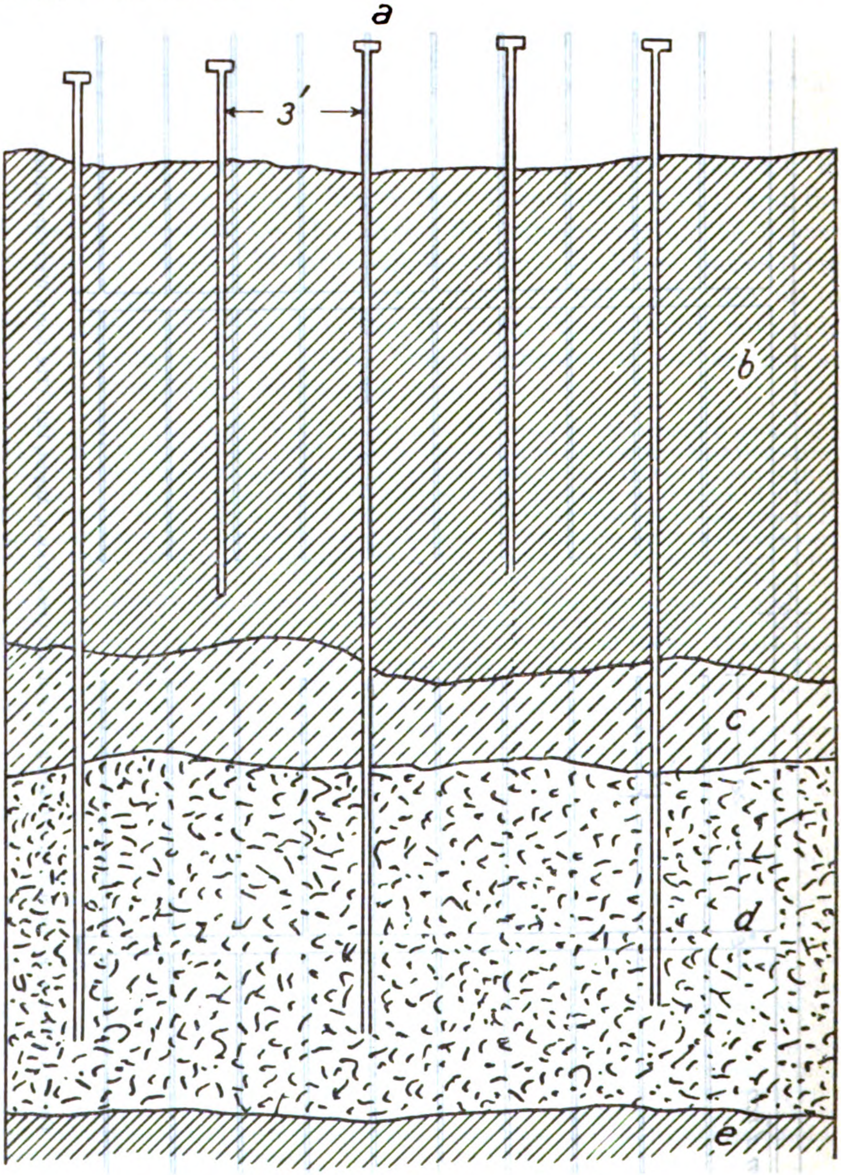

FIGURE 3.—Spacing of long and short sweaters: *a*, sweater; *b*, fine muck, 12 to 15 feet thick; *c*, thawed ground, 1 to 3 feet thick; *d*, pay gravel, 7 feet thick; *e*, bedrock.

Figures of costs and yards thawed per miner's inch are not yet available, as this is our first active season with this thawing process, and these figures will be made up when we shut down for the winter.

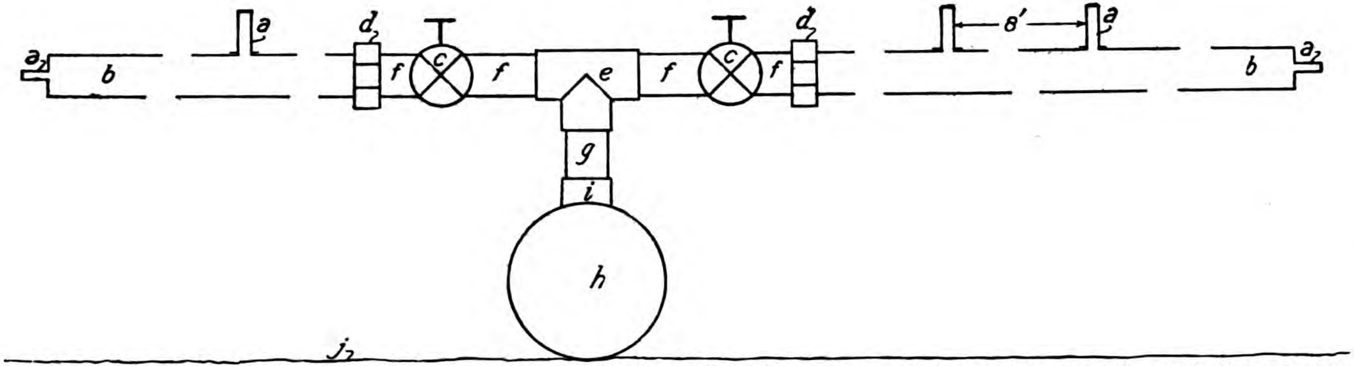

FIGURE 4.—Diagram of make-up of piping for cold-water thawing on Dominion Creek, Yukon, August, 1921: *a*, 3½-inch pipe nipples 4 inches long welded at 8-inch center; *b*, 1½-inch pipe 28 inches long; *c*, 1½-inch gate valve; *d*, 1½-inch union; *e*, 2-inch tee; *f*, ½-inch nipples; *g*, 2-inch nipple; *h*, 8-inch hydraulic pipe; *i*, 2-inch coupling, welded in; *j*, surface of ground.

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EXPERIMENTS OF FAIRBANKS GOLD MINING CO., FAIRBANKS DISTRICT.

The following account is from a special field report on the experimental work in the Fairbanks district, the report being made for the Bureau of Mines by K. T. Sparks.

Because of the high cost and incomplete results obtained in thawing frozen ground with steam the Fairbanks Gold Mining Co., which operates two dredges, decided to conduct a series of experiments with cold water during August, 1920.

TEST WITH POINTS.

The first test made with cold water consisted of connecting a water line under a 30-foot head (13 pounds per square inch) to a manifold, which in turn was connected to the thawing points by means of rubber hose. The points were of the usual steam-thawing type and were 26 feet long. The block of ground selected for the test measured approximately 30 by 60 feet and consisted of 15 feet of muck overlying 7 feet of gravel. The muck had thawed naturally to a depth of about 1 foot. The remainder, both gravel and muck, was frozen except for a streak of thawed material immediately above the line of contact between the gravel and muck. This thawed streak was 1 to 3 feet thick and was probably the result of the circulation of air in old underground workings, as a large amount of the ground being dredged on Fairbanks Creek has been mined by shaft and drifting methods. Twenty-four points were used in the thaw; they were spaced 5 feet apart, and the water was allowed to run for 36 hours. The temperature of the water at the intake was 58° F. and at the discharge from the points 42° F. At the end of the 36-hour period the ground was thawed about as thoroughly as the usual thaw with steam in this district, but there were numerous blocks (known locally as "niggers") of unthawed material. These were due, no doubt, to the water rising only as far as the thawed streak, finding a channel through this, and not rising directly to the surface.

TEST WITH SWEATER.

The second test was made by using "sweaters" made of a piece of ¾-inch pipe with an open T of the same size threaded on the upper end. The sweater does not taper to a point but is full size to the end of the pipe. Long, 24 feet, and short, 12 feet, sweaters were alternated (Fig. 3). By this arrangement the long sweaters reached to bedrock and the short ones to within 1 to 3 feet of the thawed material. The sweaters were spaced 3 to 4 feet apart. This thaw also continued 36 hours. The frozen ground was completely thawed, no blocks of frozen material being observed.

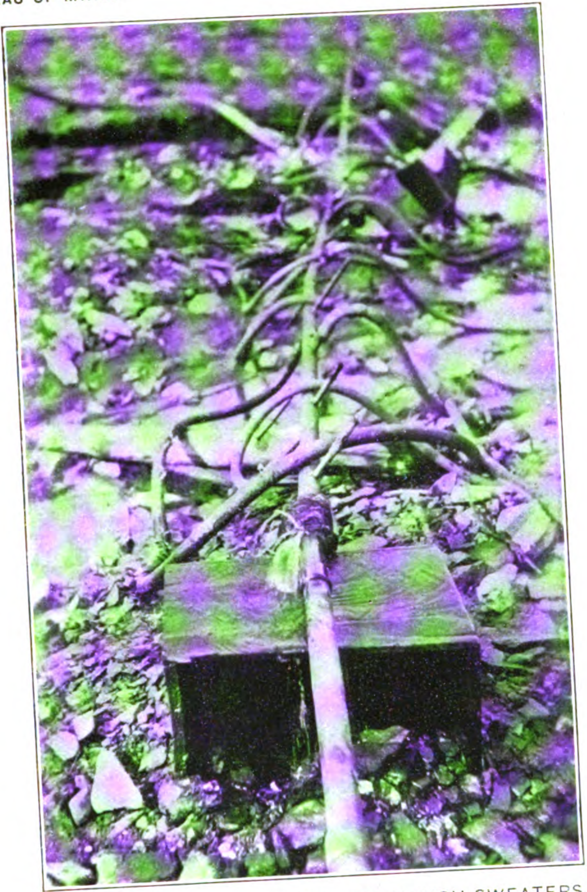
Another test was made with the same equipment and under the same conditions of water pressure, temperature, etc., but in comparison with a steam thaw on adjoining ground. Results of this test showed that with cold water the ground was thawed uniformly and thoroughly, whereas in the steam-thawed ground there were numerous blocks and ribs of unthawed material. The time allowed for cold water to thaw the ground was 36 hours and the steam 24 hours.

ARRANGEMENT OF THAWING SYSTEM FOR 1921 SEASON.

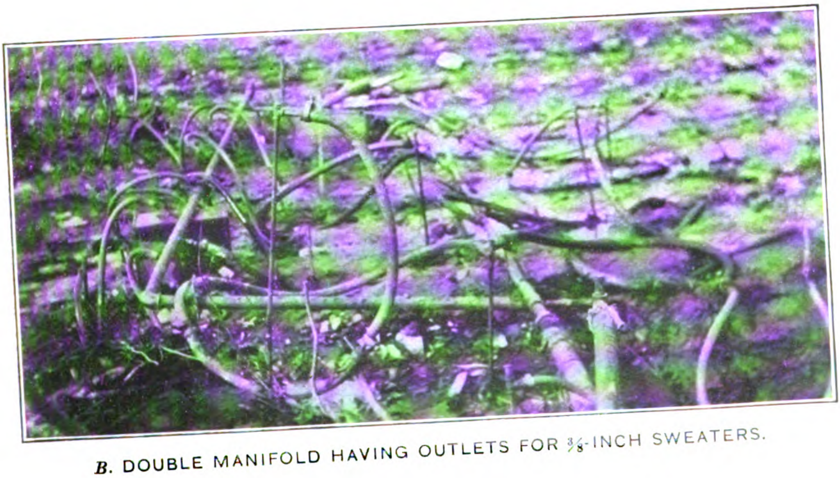
A 2-mile ditch has been constructed on Fairbanks Creek from claim No. 8 above to claim No. 1 above, which gives a head of 125 feet. This ditch supplies a penstock, from which a 10-inch steel spiral-riveted pipe leads to the claim (No. 1 above) where the water is used. Six-inch distributer pipes carry the water to convenient places for connection to the header pipes feeding the sweaters. This water can also be used for hydraulicking when there is any to be done.

MISCELLANEOUS TESTS.

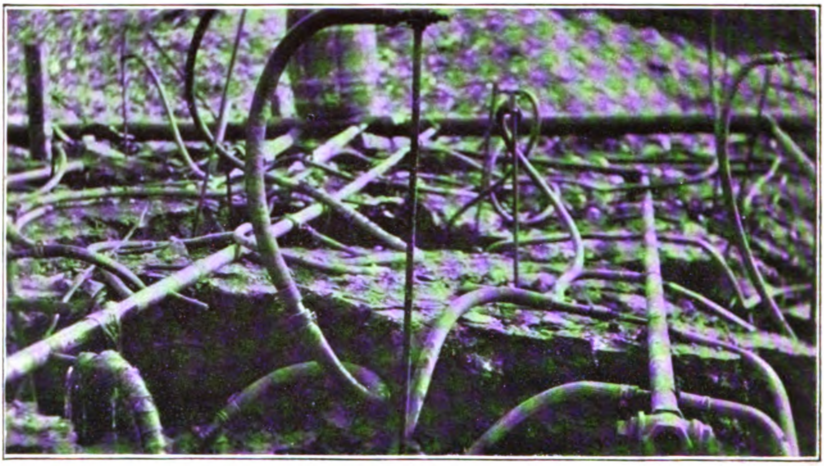
To determine the most efficient diameter of sweaters, a test was made as follows: A ⅜-inch and a ¾-inch sweater were set 6 feet apart in frozen muck. Water under a 125-foot head (54 pounds per square inch) was used and allowed to run 24 hours. The



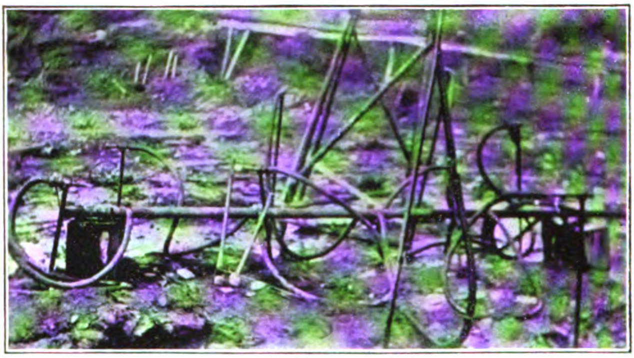
A. LONG SINGLE MANIFOLD FOR ⅜-INCH SWEATERS.



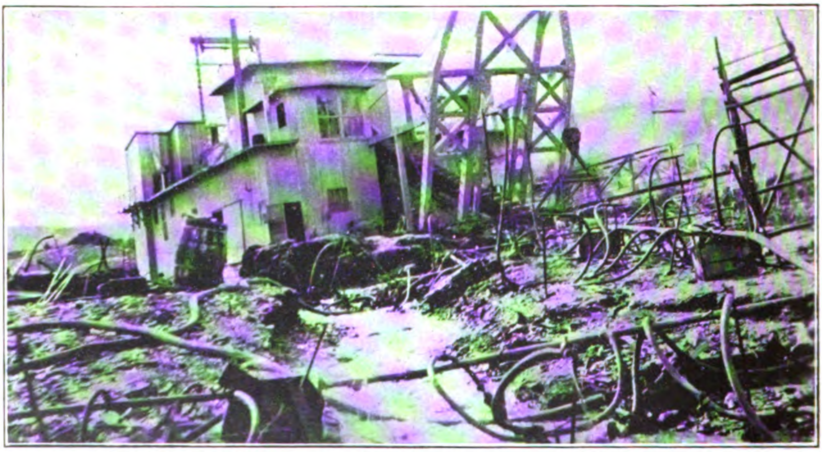
B. DOUBLE MANIFOLD HAVING OUTLETS FOR ⅜-INCH SWEATERS.



A. DOUBLE MANIFOLD FOR ¾-INCH SWEATERS.



B. SINGLE TRENCH MANIFOLD FOR ¾-INCH SWEATERS.



C. NO. 2 DREDGE ON CLAIM NO. 1 ABOVE, FAIRBANKS CREEK.

temperature of the intake water for both points was 60° F.; the temperature of the discharge water from the ⅜-inch sweater was 40° F. and from the ¾-inch sweater 43° F. Probing with a bar showed that the ⅜-inch sweater thawed an area of approximately 2,124 square inches, whereas the ¾-inch sweater thawed about 1,810 square inches. The test seemed to indicate that under these conditions the smaller sweater is the more efficient.

A test was also made, during the first week of June, 1921, to observe the results of low-temperature water. A ¾-inch sweater was set in gravel (not muck) and the water used under a 125-foot head. The temperature of the intake water was 37° F. and of the discharge water 32° F., or practically freezing. The test was run 24 hours, when the point had thawed a cylinder having a radius of 25 inches.

Another test was made with a ¾-inch sweater in comparatively coarse gravel. Water under a 125-foot head was used and allowed to run 24 hours. The temperature of the water at the intake was 60° F. and at the discharge 44° F. At the end of 24 hours a cylinder having a radius of 36 inches was completely thawed.

EQUIPMENT.

The present (1921) equipment consists of:

Three double-header pipes or manifolds, 1½-inch diameter each, having 16 outlets for ⅜-inch sweaters.

One long single manifold, 24 feet long and 1½-inch diameter, having 16 outlets for ⅜-inch sweaters.

One double manifold, 3-inch diameter, having 16 outlets for ¾-inch sweaters.

One single manifold, 3-inch diameter, having 12 outlets for ¾-inch sweaters.

Each leg of the double manifold is 12 feet long and has eight outlets. The base has a connection for a 3-inch canvas supple hose which takes water from the 6-inch distributer pipe. Plate IV, *B*, shows a general view of the double manifold.

The single manifold is 24 feet long, and has connections for 16 sweaters. It is useful when thawing across the bed of the stream flowing from the dredge pond, as it avoids frequent wading by the workman making the set-up. Plate IV, *A*, shows a view of the single manifold.

The double manifold for the ¾-inch sweaters is constructed the same as the double manifold for the ⅜-inch sweaters, except that it is made from 3-inch pipe. This larger pipe is necessary because of the additional volume of water necessary to supply the sweaters. Plate V, *A*, shows this manifold.

The single manifold for the ¾-inch sweaters is a 12-foot length of 3-inch pipe, capped at one end and having a connection for the supply hose at the other. Plate V, *B*, shows this manifold.

CONSTRUCTION AND NUMBER OF SWEATERS USED.

The sweaters are made of pipe, of the diameter required, in lengths ranging from 4 to 26 feet, and have a T threaded on the upper end. One side of the T is capped and the other has a connection for the supply hose. The T is also used as a driving cap in case a bowlder is encountered. The lower end of the sweaters is not pointed but discharges full bore. During the experiments described there were 64 of the ⅜-inch sweaters and 28 of the ¾-inch sweaters in use, or a total of 92 used in one thaw. Plate IV, *C*, shows a general view of the dredge with the sweaters in operation.

TIME REQUIRED FOR SETTING POINTS AND THAWING GROUNDS.

After the water is turned on the sweater sinks almost immediately through the first foot of thawed muck and with a little working by hand from side to side it will penetrate about 1 foot into the frozen material. From this point the progress is slower, but usually the sweater will sink to bedrock without driving in four to six hours. Two men have no difficulty in sinking 92 sweaters in an eight-hour shift. The sweater is allowed to remain until water ceases to bubble up in its vicinity, indicating that the water from the points has found an underground channel and the thaw is complete. This usually requires 36 to 40 hours.

Two men on a shift can take care of 100 sweaters and make such changes as are required. From the tests made at Fairbanks a sweater of ⅜-inch diameter under a high head was found more satisfactory. The smaller sweater thaws a larger area with less water and is also easier to sink to bedrock than one of larger diameter. There is no doubt as to the advantage of thawing with cold water as compared to thawing with steam. Although with cold water the time required to thaw the ground is somewhat longer, this is offset by the thoroughness of the thaw and the saving in cost.

CONCLUSIONS.

The different experiments and work done in cold-water thawing demonstrate that under favorable conditions the process is an assured success. It is proving of great value to the gold-mining industry of the far North and is encouraging investigation and exploitation of areas of frozen gravel that had been considered of too low grade for profitable mining.

Much remains to be learned regarding the best method of applying the water to the frozen ground. The article by Edward Pearce (p. 19) should encourage similar experiments. Undoubtedly further improvements will be made as work is attempted on a larger scale and operating costs will be reduced as better methods are developed.

WATER SUPPLY—SUPPLEMENTARY STEAM PLANT.

A number of factors must be considered in judging the feasibility of any mining venture based on the thawing of frozen ground by the use of cold water. The most important factor, other than a high enough gold content and the general conditions governing successful dredging or mining operations, is that a large quantity of water delivered at small cost is required for thawing frozen ground by the method as now used. At the plant of the Yukon Gold Co. on Gold Run, where the ground was 25 to 30 feet deep, 1,000 points were necessary to thaw the ground in front of a 7½-foot dredge. Water for these points was furnished by a large pump delivering 3,000 to 3,500 gallons per minute. About 45 men were required to operate the plant, set points, etc. Thawing with cold water was practicable during only three months of the six months' season and a supplementary steam-thawing plant was necessary in the early summer and late fall. This has been the experience of the Yukon Gold and other companies that have tried cold water.

Edward Pearce in his early experiments found it advisable to use steam in addition to water under normal temperature, but has since developed a method of artificial drainage to supplement the cold water applied by points. It is possible that a large plant might thaw enough ground in three months to last until the end of the dredging season, but the experience of the companies mentioned is that steam thawing is necessary at least in beginning operations in the spring. Ground that is thawed but not mined at the end of a season is generally frozen solid again during the winter and requires rethawing.

The number and size of dredges will depend upon the size, depth, and character of the ground to be worked; the same considerations govern the size of a thawing plant, and to some extent the cost of thawing. The latter, however, will also depend largely on the quantity of water available and whether it can be delivered under natural head or whether pumping will be necessary.

It should be understood that on some creeks where mining is carried on the water available during the greater part of the season would be insufficient to thaw ground for large-scale work, even though the available water was constantly reused. The Yukon Gold Co. found that 3,000 gallons or more of water per minute was required to thaw ground ahead of a 7½-foot dredge. Figures on the quantity of water required at other operations are not at present available.

It is obvious that when water under natural head is not available, or is obtainable only through a great outlay for the construction of ditches, the cost of pumping water in districts where labor and fuel costs are high might prohibit the profitable thawing of frozen gravels low in gold.

The success of thawing frozen ground by the application of cold water (water at natural temperature) under pressure depends, therefore, on securing a large quantity of water that can be delivered to the ground at low cost.

NEED OF COMPREHENSIVE DATA.

Tracts suitable for dredging in the far North will contain areas that differ as follows:

1. Wholly frozen.
2. Wholly thawed.
3. Thawed from the surface to within a few feet of bedrock and from there on completely frozen.
4. Frozen some distance from the surface and to within a few feet of bedrock and from there on thawed.
5. Containing irregular blocks of frozen and thawed gravel extending from surface to bedrock.

Enough information on the action of cold water on ground having these different characteristics is not yet available. Little is known regarding the amount and the circulation of underground water. The water delivered to bedrock by a point may not rise near the point, but may pass several points in succession and come to the surface 50 feet or more away, indicating an underground circulation. The result of this circulation is to leave blocks of unthawed ground which require the placing of additional points between those first set. It is in such cases that steam thawing has proved useful in supplementing water thawing.

Some experiments in cold-water thawing have been made on ground that has previously been mined by drifting or other methods, or on frozen ground adjoining thawed spots or close to banks exposed in open pits. It is not clear what influence these conditions would have in aiding the thawing of the frozen gravel. It would seem, however, that the thawing with cold water of areas where there is little or no underground circulation would require a longer time than the thawing of frozen ground close to thawed areas and open faces.

Most frozen areas that are mined contain irregular patches of frozen and thawed ground, as mentioned by McCarthy in describing his experiments in the Yukon. Aside from this, the circulation of underground water in these areas seems to have received little study, yet it is a matter likely to have considerable bearing on the successful application of cold-water thawing.

Existing surface streams may be used to advantage by preparing drainage ditches instead of allowing the water to find a natural course through the ground.

In the Nome district it was noticed that considerable water was lost from surface ditches by seepage through the frozen muck and gravel. This water, forming or following natural channels of circulation through the frozen ground, gradually cut its way to bedrock. The effect of this thawing was in part responsible for an ambitious scheme proposed about 1910 or 1912 for draining a large part of the Nome tundra. The proposal had many advocates at the time, but the cost of the work prevented its being carried out. It is evident, however, that the thawing of frozen ground can be greatly aided by a drainage system of some kind, either following natural underground channels of circulation or by forming artificial drainage ditches.

A thorough study of drainage either by ditches or by pumping, or by some system combining both methods, should be made in any further experiments of thawing frozen ground with water under natural temperature as it seems that in this direction improvements can be expected and expenses reduced.

TEMPERATURE OF WATER.

Any method for thawing frozen gravel necessarily depends on the application of heat in some form. The experiments discussed in this paper indicate that the use of large quantities of water at a temperature of 50° to 60° F. at intake and 10° to 12° F. less at outflow is the cheapest and most efficient way thus far known of applying this heat.

It must be recognized, however, that in the far North the thawing season, when the natural temperature of the water is 50° F. or more, is short; it lasts only three months, from the middle of June to the middle of August. In some seasons the highest temperature of the water in ditches and ponds has averaged only about 40° F. and in experiments with cold-water thawing during those seasons it was necessary to heat the water before applying it. Gibson (p. 17) had to raise the temperature of the water from 44° to 54° F. in order to obtain satisfactory results, as did the Yukon Gold Co. in some of its work. Burrall points out that during the summer the temperature of the water ranged from 40° to 70° F., and that although cutting down the velocity of the water caused the temperature of the discharge to fall below 40° F. greater efficiency was obtained by having the temperature of the discharge water above this figure.

Statements as to the percentage of ice in a cubic yard of the frozen gravel do not agree and therefore estimates of the number of heat units required to thaw the frozen material differ. It should be recognized that the figures are generally only estimates, and while they are useful in indicating approximately the heat units required they are useless for any refinement of calculations.

COST OF COLD-WATER THAWING.

The cost of cold-water thawing is a matter of great interest, but unfortunately the data available are insufficient. At the Yukon plant, where pumping was necessary but the company had available a large amount of power, the bare operating cost indicated was 10 to 14 cents a yard, without any charges for overhead or the amortization of the plant. In the Nome district the estimated cost for large-scale operations is 4 cents or less per cubic yard, this estimate assuming the availability, with no charge for it, of a large quantity of water under natural head. Estimates in other districts under varying conditions run from 5 to 10 cents a yard. As in all mining operations, the cost will depend largely on local conditions, and chiefly whether water is available under a natural head or will have to be pumped. The recent work of Pearce, following improvements in his method of thawing ground, shows a much lower operating cost, the figures he gives being less than 1½ cents a yard for 20,000 yards thawed.

NEED OF INVESTIGATION.

Each of the features mentioned, as well as all others that govern successful placer mining, should be given a careful study by the examining engineer or mine operator. When mining investment is preceded by a careful investigation of every phase of the venture there can be reasonable expectation of profits. At times, even after fairly careful though hurried investigation by well-intentioned men, the returns fall short of anticipations, but without careful investigation by men of experience a so-called investment in a mining venture becomes merely a wild gamble. Especially is this true when the investor is invited to participate on the basis of glowing terms used by an irresponsible promoter.